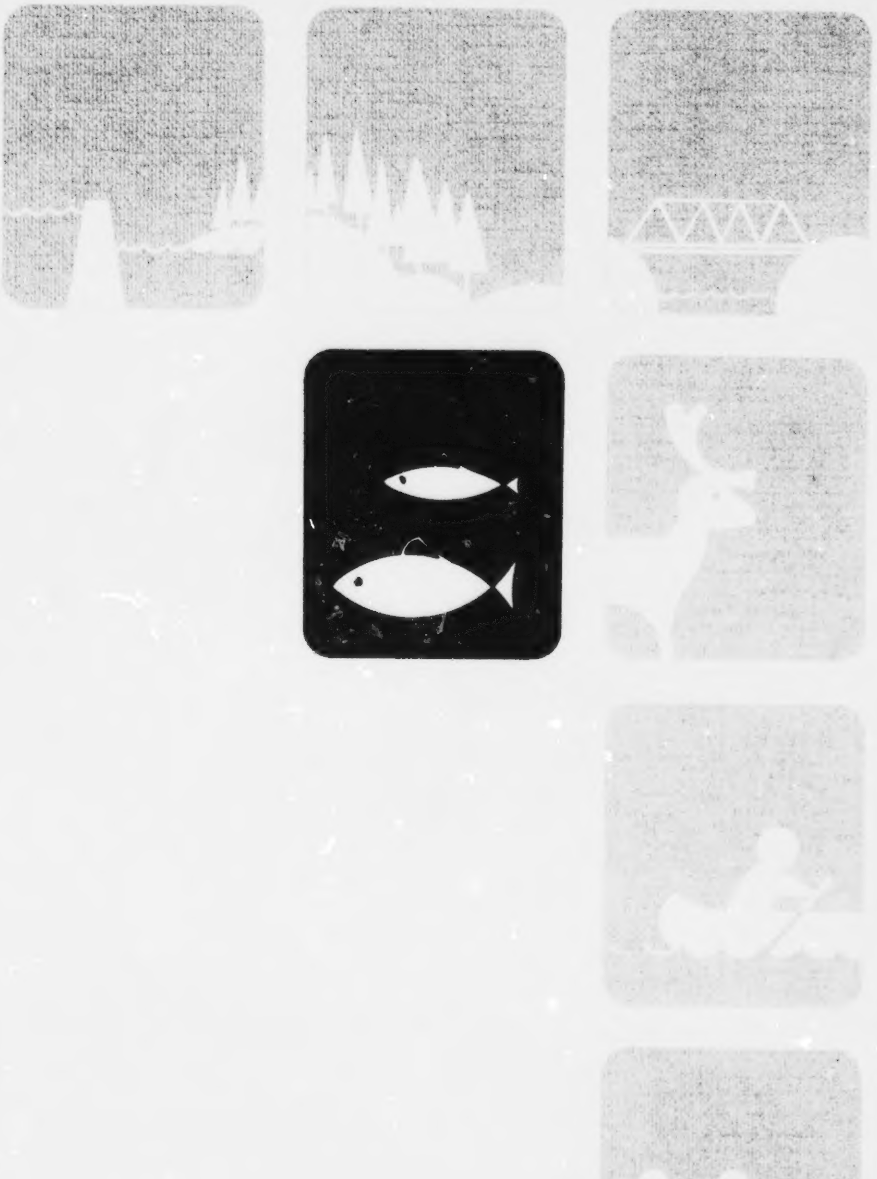

lake winnipeg, churchill & nelson rivers study board CANADA MANITOBA 1971-'75

fisheries and limnology

vol.1

technical report appendix 5

LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

APPENDIX 5 - FISHERIES AND LIMNOLOGY STUDIES, VOL. 1

A - SUMMARY OF FISHERIES-LIMNOLOGY INVESTIGATIONS ON SOUTHERN INDIAN LAKE

B - THE MORPHOMETRY OF SOUTHERN INDIAN LAKE: PRESENT CONDITIONS AND IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

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SUMMARY OF
FISHERIES-LIMNOLOGY INVESTIGATIONS
ON SOUTHERN INDIAN LAKE

by

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Winnipeg, Manitoba
February, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

INTRODUCTION

Manitoba Hydro intends to divert the flow of the Churchill River out of Southern Indian Lake into the Nelson River via the Rat and Burntwood River systems. This development will require the impoundment of Southern Indian Lake to raise the level by at least 10 or possibly 13 feet. This report examines the fisheries and limnology of Southern Indian Lake as they exist prior to development, and it attempts to predict the effects of the raised levels and changes in flow patterns on the aquatic ecosystem and particularly the commercial fishery.

An extensive field program was initiated in the spring of 1972 with most studies being completed on the lake by October of the same year. Field investigations on the chemical budget, primary production and the commercial fishery were continued through the summer of 1973. This summary emphasizes the major conclusions of eight individual task reports which are available as appendices to the summary. These task reports are entitled:

1. Morphometry of Southern Indian Lake: present conditions and implications of hydroelectric development.
2. Hydrography of Southern Indian Lake: present conditions and implications of hydroelectric development.
3. Southern Indian Lake: sedimentary environments, recent basin history, and implications of inundation and diversion.
4. Phytoplankton and primary production in Southern Indian Lake.
5. Preliminary report on zooplankton study in Southern Indian

Lake.

6. Zoobenthos survey of Southern Indian Lake.
7. The fisheries of Southern Indian Lake : present conditions and implications of hydroelectric development.
8. The fisheries of Southern Indian Lake: exploitation and reproduction.

The task reports develop in detail the data and conclusions which are presented in abbreviated form here. A more complete appreciation of the present status of the lake and the impact of the development can be gained by reading the appendices.

PRESENT CONDITIONS

The Churchill River rises in eastern Alberta on the Cretaceous sediments of the Interior Plains and flows onto the Precambrian Shield in eastern Saskatchewan and Manitoba. Before entering Hudson Bay at Churchill, Manitoba, the river drains a total of 115,000 square miles making it one of the truly great rivers of Canada. In northern Manitoba the Churchill River widens to become Southern Indian Lake (approximately 56°45' to 57°40'N; 98°10' to 99°30'W). At Opachuanau Rapids, the Churchill delivers a mean annual discharge of 31,500 cfs to Southern Indian Lake. At Missi Rapids the point of exit, the mean annual discharge is 35,500 cfs. Thus the Churchill River contributes 92% of the total inflow to the lake. The northern location of the lake imposes a relatively harsh climate on its environs. The mean annual temperature is 25°F or -4°C. ice-free season in 1972 extended from June through October. Mean annual precipitation is 15-17 inches of which approximately one-third falls as snow. Mean annual evaporation from the lake surface is thought to be similar to mean annual precipitation making inflow and outflow the only significant components of the hydrological budget.

Southern Indian Lake has a total water surface area of 734 square miles and a mean depth of 30 feet (maximum depth 121 feet). Total length of shoreline is 1350 miles (including islands) and total volume is 14 million acre-feet. To facilitate interpretation of the data gathered from as large an area as Southern Indian Lake, the lake was divided into 7 different geographical regions according to basin structure and chemical impact of the Churchill River (Figure 1). The large surface area (long fetch) and shallow mean depth of these regions allow efficient wind mixing, and there is no significant thermal stratification during the summer except in some small isolated bays. At channel constrictions in the lake relatively strong hydrographic slope currents add to the turbulence and mixing action. Water temperatures remain close to mean atmospheric temperatures through the ice-free months. With no stratification in summer, relatively low algal production, and relatively rapid water renewal (approximately three months for the Churchill River plume) oxygen values are at or near saturation in all seasons. Although Southern Indian Lake is situated on the Precambrian Shield, the dominant surface materials in Northern Manitoba are glacio-lacustrine clays. Weathering of these surface materials and the large discharge of the Churchill River result in high turbidity and low water renewal time for the lake. These two limnological features make Southern Indian Lake and other Churchill River lakes quite distinctive from "typical" Shield lakes.

Limited studies on sedimentation in Southern Indian Lake indicate that much of the sand and silt contributed by the Churchill River is deposited soon after entering the lake while smaller proportions of the total clay brought in is retained. Bottom topography and exposure to wind are dominant factors controlling sediment distribution with the result that shallow bays well protected from wind and currents are sites for sediment deposition while deeper offshore areas often have low deposition rates. Interpretation of sediment cores from Southern Indian Lake suggest that there have been relatively recent disturbances within

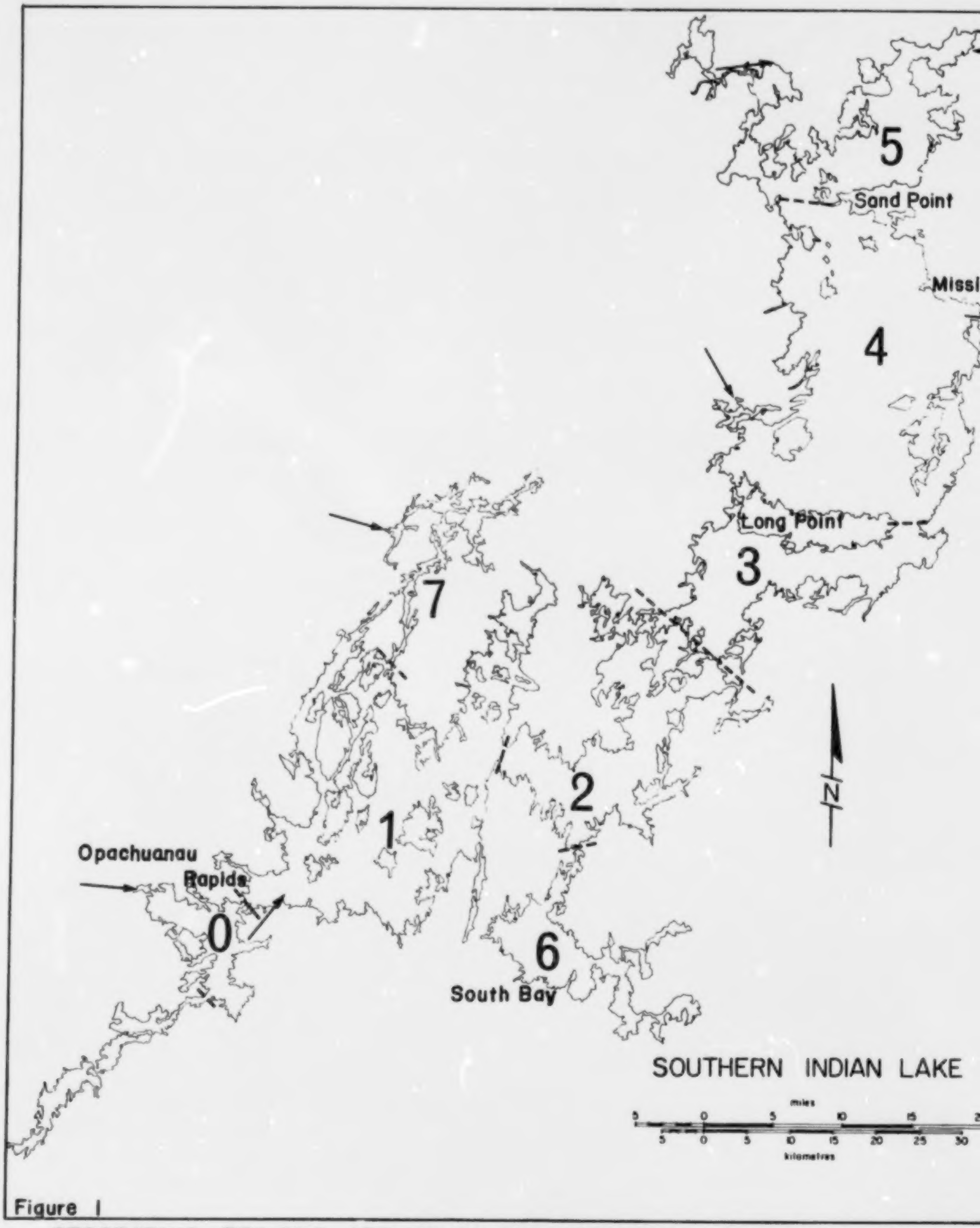

5
Sand Point
Missi
4
Long Point
3
7
2
1
Opachuanau
Rapids
0
6
South Bay
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 2
5 0 5 10 15 20 25 30
kilometres

Figure 1

GEOGRAPHIC REGIONS SET UP BY THE FISHERIES LIMNOLOGY COMPONE

(note: arrows indicate direction of flow of major streams)

the Churchill River basin. The most significant of these disturbances may have been related to the installation of hydroelectric developments upstream in the Churchill Basin. A sediment core taken from a region unaffected by the Churchill River does not exhibit any recent changes.

Water mass formation is an important aspect of the general limnology of the lake. The Churchill River is relatively high in sodium and potassium concentrations and low in calcium and magnesium compared to local Shield waters which reflect the weathering of carbonate-rich pro-glacial lake sediments. This distinctiveness of the major inflowing water types allows the intensity of horizontal mixing to be appreciated. Regions 5, 6, and 7 (the region north of Sand Point, South Bay and the northwestern region of the lake) have demonstrably little interchange with the Churchill River. The distribution of water masses within the lake has been further defined by examination of biological populations, especially the zooplankton.

The number of zooplankton species found in the lake was extremely high reflecting the complex nature of the multi-basin lake. The species list for the lake is similar to that for the Laurentian Great Lakes and it closely resembles that for Lake Winnipeg. The distribution of zooplankton species concurs with chemical data, indicating that regions 5, 6 and 7 have very little interchange with the Churchill River. In addition, zooplankton distribution shows that there is a general east-west differentiation along the length of the lake within the main lake regions, 1-4. The distribution of zooplankton suggests that the main Churchill River plume occupies the eastern portion of the lake while the western side reflects the stronger influence of local drainage.

The Churchill River is the overwhelming source of nutrients to the lake. Although concentrations of nutrients in the river are similar to those in local streams, the large discharge yields a very high annual nutrient loading. The highest loading is confined to those lake regions directly influenced by the Churchill River (regions 1-4) where calculated annual loading exceeds 0.5 g phosphorus/m^2. South Bay (region 6), north of Sand Point (region 5), and the northwestern region (region 7) of the lake have very much lower loading rates (less than 0.03 g P/m^2 annually). These low-loading regions have very little interchange with the Churchill River and have distinctive chemical (major ions) and biological properties as discussed earlier.

Despite high nutrient loading in the main lake, phytoplankton growth is not excessive as algal standing crops are comparable to those in oligotrophic lakes. Fine suspended clays restrict light penetration which frequently limits nutrient utilization and phytoplankton growth over much of the lake. As the Churchill River passes through the lake, suspended materials are sedimented and the water becomes more transparent. Maximum algal standing crops and primary production occur in the large basin north of Long Point (region 4) where the combination of relatively high light penetration and nutrient-rich Churchill River water produce the best conditions for algal growth in the lake. Similar light conditions are found north of Sand Point (region 5) and allows this region of the lake to sustain algal growth comparable to several lake regions influenced by the Churchill River despite the low nutrient loading to the region. South Bay has low light penetration and low nutrient loading and consequently has by far the lowest algal production in the lake.

The average population density of benthic invertebrates (bottom fauna) in Southern Indian Lake was substantially greater than densities in most Shield lakes in the region. Highest densities occurred in the main lake areas influenced by the Churchill River plume reflecting the positive influence of the physical and chemical parameters of the Churchill River. The two most abundant benthic organisms were the amphipod *Pontoporeia affinis* and midges (Chironomidae). Both are excellent whitefish food. *P. affinis* was reasonably abundant in all areas except South Bay, but highest densities were found in regions strongly influenced by the Churchill River.

Total numbers of fish taken by experimental gangs of gillnets indicated that Southern Indian Lake has a higher production of fish (numbers) than other Shield lakes in the region although rates of growth and condition of fish were not exceptional. Whitefish (*Coregonus clupeaformis*), walleye (*Stizostedion vitreum*), and northern pike (*Esox lucius*) were the most abundant commercial species in the experimental gillnet collections with whitefish dominant in all regions excepting South Bay. "Coarse" fish species (white sucker *Catostomus commersoni*, longnose sucker *Catostomus catostomus*, burbot *Lota lota*, perch *Perca fluviatilis*, etc.) were in reasonably good supply with white sucker predominating in almost all areas. Average numbers of whitefish, the primary commercial species, taken per experimental gillnet set were greater than those taken from any other Shield lake in the region with the exception of Playgreen Lake which also has a large river (the Nelson) flowing through it. In the regions of the Southern Indian Lake directly influenced by the Churchill River (regions 1 to 4) the average value is in fact considerably larger than that for Playgreen Lake.

Although whitefish appear to spawn in almost all areas of the lake in depths of four to 19 feet over broken rock and boulders, there is a concentration of spawning whitefish in the area north of Long Point (region 4). There are some indications that whitefish migrations of up to 40 miles to the area may occur. Large concentrations of spawning walleye were found in eight tributaries to Southern Indian Lake. Walleye from all parts of the lake appear to migrate to these streams.

The commercial fishery is very productive (2.5 lb/acre), exceeding the yield of other large Shield lakes in the region and approximately equalling that of the more productive Churchill River mainstem lakes in Saskatchewan (Figure 2). The winter fishery has been in operation since 1942 with an average annual production of 450,000 pounds, 95% of which are whitefish. This winter fishery operates only in region 4. Depending on methods used "break-even" requirements for operators ranged from 2,400 pounds using dog teams to 7,500 pounds using bombardiers, with production costs ranging from 6.2¢/lb to 8.8¢/lb. The summer fishery, in operation since 1950, presently produces 700,000 pounds a year, 86% of which are whitefish and 13% walleye. The summer fishery operates over the entire lake, but regions 1, 2 and 4 produce the highest landings. Again, depending on methods used the break-even points for operators ranged from 5,263 pounds (single fishermen) to 13,442 pounds (paired operators and additional labor). Unit cost of production ranged from 6.82¢/lb to

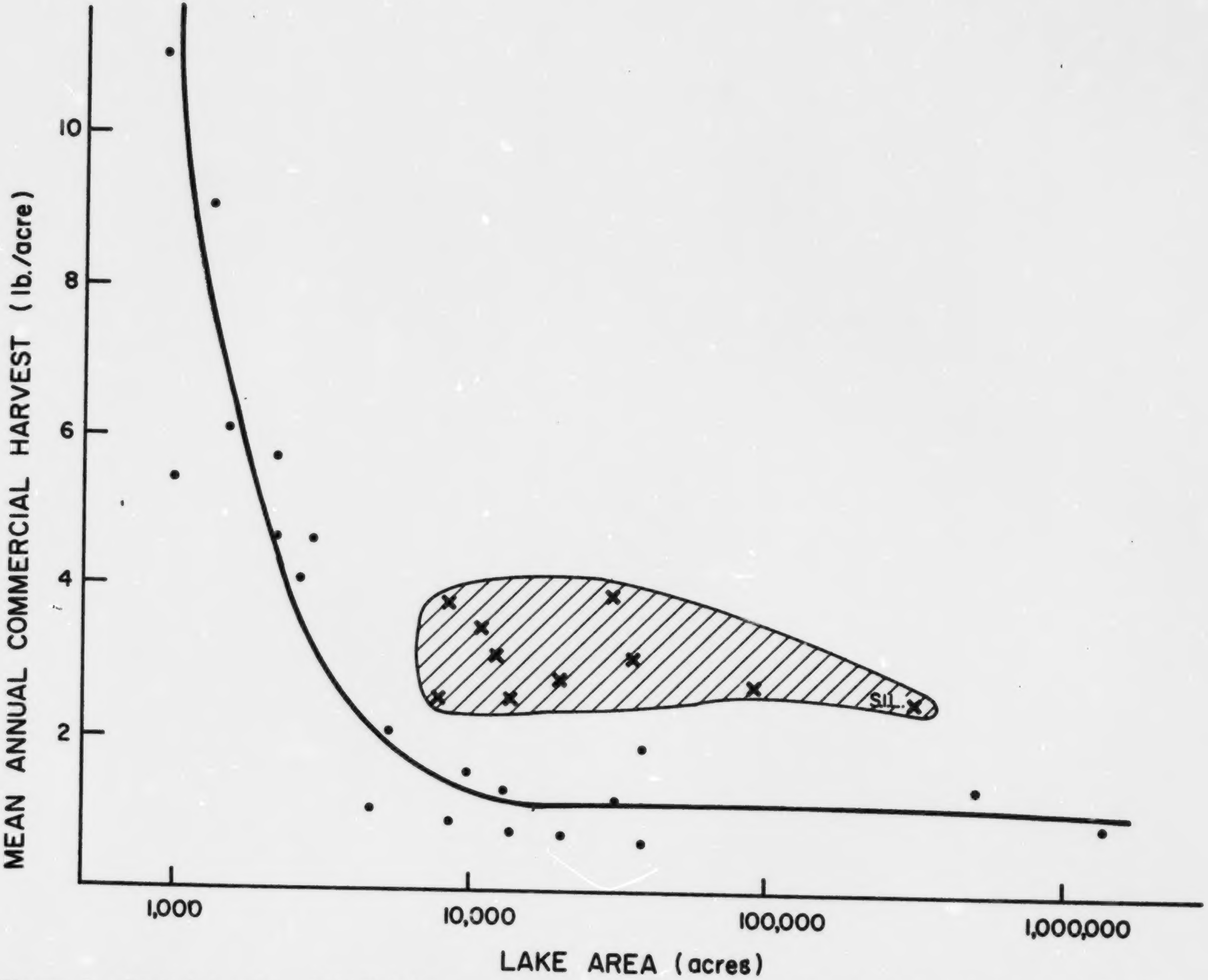


Figure 2. Recorded commercial fish harvest on the basis of lake area (logarithmic scale) from 20 lakes on the the Precambrian Shield (•) and 10 lakes on the Churchill River mainstem (x) in Saskatchewan and Manitoba. Lines are fitted by eye (after Koshinsky, 1971).

7.97¢/lb. The average gross income for a fisherman on Southern Indian Lake has increased from an average of $825/year during 1950-51, to an average of $2,409/year in 1972-73 (this includes winter and summer seasons). Despite the current high productivity of the commercial fishery, there is no evidence of overexploitation. The fishermen presently are not taking the allowable quota, but effort not fish productivity is the problem. In fact, the maximum sustainable yield is probably significantly in excess of the present quota.

Southern Indian Lake has the potential to support an excellent trophy pike sport fishery. Although no trophy sized walleye were captured, sport fishing for walleye is also considered to be above average.

SUMMARY OF PRESENT STATE

The previous discussion of the present limnology of the lake has shown that the Churchill River has a positive effect on the productivity of nearly every trophic level from phytoplankton to fish. Table 1 summarizes and emphasizes this relationship. In this table the lake region with the maximum value for each parameter is rated 100% and the values for all other regions are given in proportion. Columns (1), (2), and (3) relate to the suitability of conditions for algal growth. The Churchill River regions have superior conditions and the phytoplankton biomass (4) reflects this directly. Relationships between river influence and zooplankton biomass (5) is less clear, but high flow can have a negative influence on zooplankton populations and may account for some of the scatter in data. The standing crops of zoobenthos (6) have a distribution similar to that of phytoplankton with higher values occurring in regions 1-4. Although zoobenthos was only sampled once, the fairly long life cycle and the low mobility of these animals should allow them to be reasonable integrators of productivity. Fish (7) in contrast are highly mobile, but there is still a good indication that on the average the Churchill River regions have somewhat higher fish production than other regions. Any of these biological parameters alone cannot be used to evaluate the general productivity of an area as each has its own inherent problems of measurement and relevance. However, a composite of all four should render a reasonable indication of productivity. In column (8) the average value for each region is entered. As no region had maximum values for each parameter, there is no 100% rating; but the regions influenced by the Churchill River clearly have the greater intensity of production. In regions 1-4, the waters are three times as productive as in region 6; and they are 20% more productive than the other Shield waters. When this relative production factor (8) is applied over the area (9) of the different regions, the importance of each lake region to the total production (10) of the lake can be appreciated. The concentration of commercial fishing effort in regions 1, 2 and 4 is perhaps best understood in relation to these values which indicates that region 4 accounts for approximately 40% of total biological production. Region 4 presently yields 75% of the total commercial catch (Table 2, p. 23) while regions 1 and 2 account for most of the remainder.

Table 1. Evaluation of parameters indicative of general biological productivity of lake regions under pre- and post-impoundment conditions. In columns 1-8, 100% = maximum value in the lake at present and other numbers are proportional. In columns 9 and 10, numbers are percent of total (= 100) under present conditions. Significance of these parameters is discussed in appendices.

Source	Region	(1) Nutrient loading (annual)		(2) **Light** (June-Oct.)		(3) Conditions for phytoplankton production Average of 1)&2)		(4) Phytoplankton biomass (June-Oct)		(5) Zooplankton settled volume (August)	
		pre	post	pre	post	pre	post	pre	post	pre	post
Churchill	1	100	100	65	65	83	83	68	68	46	46
	2	96	96	70	70	83	83	76	76	83	83
River	3	94	20	80	130	87	75	85	60	51	70
	4	90	20	100	150	95	85	100	80	100	50
Local	5	4	4	100	100	52	52	59	59	50	50
Drainage	6	3	94	70	40	37	70	19	60	26	85
	7	-	-	-	-	-	-	-	-	82	82

Source	Region	(6) Zoobenthos all organisms (July)		(7) Fish all species (July-Sept.)		(8) Relative production Average of 4), 5), 6), 7)		(9) Area % of total	(10) % of total lake production produced in each region	
		pre	post	pre	post	pre	post		pre	post
Churchill	1	100	100	94	94	77	77	25	26	26
	2	36	36	100	100	74	74	12	12	12
River	3	68	40	87	75	73	60	11	11	9
	4	65	40	71	60	84	60	33	38	27
Local	5	52	52	99	99	65	65	11	9	9
Drainage	6	30	40	30	60	26	60	6	2	5
	7	50	50	60	60	64	64	2	2	2
									100	90

IMPACT

During the course of this study changes by Manitoba Hydro have been made to the details of their proposal. Therefore, before impacts can be identified and evaluated, the post-development water level and flow conditions on which assessments are based must be briefly defined. To augment flow through their Nelson River power plants, Manitoba Hydro intends to divert the Churchill River through the Rat-Burntwood River system to the Nelson River. To accomplish this the level of Southern Indian Lake must be raised by at least 10 and possibly 13 feet by the construction of a control structure at Missi Rapids, the natural outlet from Southern Indian Lake. The higher water level and a diversion canal from South Bay to Issett Lake will permit up to 30,000 cfs to be diverted into the Rat River by gravity flow. The discharge through South Bay will be regulated by a control structure at Notigi Lake on the Rat River. By the interim license, minimum allowable flows through Missi Rapids will be 1,500 cfs in the winter and 500 cfs in the summer, but the long-term average annual discharge at Missi Rapids, based on the historical records should be nearly 6,000 cfs.

Higher water levels on Southern Indian Lake will increase water surface area by 28% (734 to 936 sq. mi.), volume by 30% (14 million acre-feet to 20 million acre-feet) and mean depth by 12% (30 ft to 34 ft). The increases in mean depth are not considered to be sufficient to lead to prolonged thermal stratification in the summer; and the lake will continue to be isothermal and well oxygenated during the summer.

Inundation resulting from these higher levels will be the prime source of impact to regions 1, 2, 5 and 7. Inundation will also affect the water quality of regions 3, 4 and 6; but altered flow patterns will likely have a greater impact on water chemistry especially in the long term. The lower lake regions, 3 and 4, below the point of diversion will have total flow-through reduced to 20% of the present level on the long-term average. If minimal allowable discharges were enforced for a year or longer, flowthrough would be reduced to 3% of the present level. Assessment has been based on the higher figure, but operation at minimum discharges is highly probable and impact in that case would be much more drastic than the following discussion suggests. South Bay, region 6, which now receives negligible amounts of Churchill water, will receive most of the river flow under diversion.

The water chemistry of regions 3, 4 and 6 will be significantly altered by diversion. Greatly reduced inflow of Churchill River water will permit local drainage to more strongly influence regions 3 and 4. Increases in total dissolved solids, calcium and magnesium will occur. In South Bay the opposite changes will be observed. Faunistic and floristic changes will likely accompany these changes. Nutrient loading to regions 3 and 4 will be drastically reduced (from 0.53 g P/m^2 to 0.08 g P/m^2). However, sediment loading and turbidity will also be reduced in the long term, and an improved light environment and longer residence time for the water will offset to a certain extent the reduction in nutrient loading. Annual algal production in regions 3 and 4 is expected to decline to one-half to two-thirds of the present level. By drawing analogies with the present limnology, zoobenthos and fish production will probably decline as inflow from the Churchill River declines. The longer residence time (increasing from less than three months to more than two years) may lead to increased standing crops of zooplankton. The positive influence of Churchill River flow which was discussed earlier will increase the productivity of region 6, but the beneficial effects may not extend over the whole area. Phytoplankton and zooplankton will be largely imported from region 2, but increased standing crops of zoobenthos will represent a real boost in production and fish production will reflect this.

Inundation will affect water quality in all regions of the lake, but the changes will not be as drastic as those associated with diversion. Shoreline erosion will represent a new source of nutrient and sediment loading. In reservoirs in other climatic and physiographic regions nutrients released from soils and decaying vegetation have often led to increased post-impoundment production at all levels in the food chain. However, nutrient loading to Southern Indian Lake is already quite substantial; and light appears to limit algal production much of the time over most of the lake. Overburden around Southern Indian Lake is predominantly glacio-lacustrine clays. The new shorelines have a great potential for releasing sediments and causing increased turbidity. As light penetration is now critical in many areas of the lake, the increased turbidity is likely to negate any benefits of increased nutrient supply. For these reasons, a short-term increase in total production at all trophic levels is not expected to follow the impoundment of Southern

Indian Lake. In fact increased turbidity and sedimentation caused by shoreline erosion will cause a decline in production in some lake areas especially near shore.

In inundated areas with substantial vegetative cover, inundation could pose some special problems. Decaying vegetation creates an oxygen demand and can lead to reduced oxygen levels which are detrimental to fish and zoobenthos. Very low oxygen levels are currently observed under ice in the Moose Lake portion of the Kettle Reservoir where flooding was most extensive and water exchange with the Nelson River is limited. Similar conditions may occur in those portions of Southern Indian Lake where flooding is extensive and flushing poor. Portions of region 5 are most likely to produce these conditions as well as isolated bays all along the new shoreline. Region 5 has some extensive areas of marsh and fen along the Waddie and Muskwesi Rivers which will be inundated. Organic materials from these areas also pose the threat of floating debris to fishing and navigation (floating islands). Although debris will be produced from all new shorelines, this region appears to have the greatest potential for producing floating debris.

Fish are integrators of conditions existing in a lake over a number of years and hence do not show as immediate a response to a new situation as do benthos or plankton. The predicted decline in planktonic and zoobenthic production in regions 3 and 4 will eventually lead to reduced fish production, but the decline will be more gradual and may not be in proportion. In addition to reduced food availability in regions 3 and 4, the two commercially important fish species, whitefish and walleye, will likely have reduced spawning success. Suitable spawning sites for whitefish are likely to be limited at least until inundated areas have cleared, but stream spawning walleyes should not be significantly hampered providing suitable sites are available at higher elevations in spawning streams. The diversion could, however, disorient migration patterns of both species and hence negatively affect spawning.

The production of northern pike should increase following impoundment and diversion. Inundated areas will provide pike spawning habitat and any decrease in the growth rate of prey species will prolong their susceptibility to pike predation. Although pike are not considered to be commercially desirable at present, they might become so at least until the lake stabilizes after impoundment. Sport fishing for pike should remain of a high calibre. Although spawning sites for sauger (_Stizostedion canadense_) may be scarce, other conditions following inundation may be beneficial to this species. However, sauger in Southern Indian Lake are reaching the northern limits of their range, and it is doubtful that they could become commercially valuable.

Impoundment and diversion will cause generally lower productivity for Southern Indian Lake. Maximum declines will occur in regions 3 and 4 where greatly reduced nutrient loading will lead to reduced primary production. The decreased production at the primary trophic level will reduce production at higher trophic levels. In lake regions unaffected by diversion there will likely be decreases in production especially in the short-term while eroding shorelines increase turbidity. The limnological impacts discussed above are summarized in Table 1 in which the relative gradation of critical parameters is evaluated as for the present condition. It must be cautioned that numerous assumptions must be made to construct a table of this fashion, but it is thought to be a reasonable representation of the relative production of lake regions after development although the precision of these estimates is necessarily less than for the present condition. If no significant changes are expected after, identical values are entered under pre and post. Table 1 should be interpreted as representative of the lake 20 years post-impoundment. Predictions concerning immediate post-impoundment conditions are very uncertain, but general impact in the short-term is likely to be more severe than Table 1 indicates. The table emphasizes that maximum impact will be in regions 3 and 4 where some parameters will be reduced to two-thirds of their present value. The distribution of productivity in the lake is more equitable after development than before, but this has been accomplished by making two of the most productive areas less productive. Overall biological productivity in the lake will fall by approx. 10% (see column 10). To evaluate production by region, the lake area remains constant as it is not possible to predict these parameters in flooded areas and production there will not be harvestible.

Commercial fishing will become more difficult following impoundment. Until fishermen have learned the locations of debris-free areas, loss of nets could be high and unless clearings for boat landings are made at regular intervals and at fish camps, safe passage for the fishermen on the lake is uncertain and commercial fishing will become less economical. Even if these methodological problems are surmounted, a decline in the commercial fishery can be expected. The location of present fishing grounds closely match the areas of high biological productivity, and the choice of fishing sites by fishermen is determined by their success (catch per unit effort). In the future many of the presently more productive areas will have substantial reductions in their potential (Table 1). If fishermen maintain their present level of effort in the same areas now fished their yield will decline. This is summarized in Table 2, where it is assumed that commercial yield will decline in proportion to biological productivity in regions 3 and 4. Even if region 6 makes substantial gains in productivity and potential yield after diversion, the smaller area of this region makes it impossible for these gains to offset the losses in region 4. Because the present commercial fishery is concentrated in region 4, the region of maximum impact (Table 1), the percentage decline in the commercial fishery of Southern Indian Lake will be greater than the overall decline in biological productivity.

The decline in yield could be offset if the total effort applied to the fishery increased, i.e. decline in catch per unit effort can be offset by more effort. There is no evidence of overexploitation by the commercial fishermen now, and it is likely that increased effort would not adversely affect the fishery. Unfortunately the need for increased effort will probably result in presently marginal operators becoming discouraged and leaving the fishery. This human element is likely to amplify the decline in the commercial yield as total effort also declines. This is especially true in the short term when catch per unit effort will suffer additionally while fishermen attempt to locate concentrations of fish under the new regime. Compilation of these problems make it likely that the fishery may never again reach its present level unless the economics of the market change markedly.

Table 2. A breakdown of commercial yield of whitefish and walleye from different regions of Southern Indian Lake (Pre) with an estimate of commercial yield of these species from the same regions following diversion and impoundment (Post). Pre-impoundment values are based on the results of the 1972-73 winter fishery and the 1973 summery fishery.

Region	Area (acres)	Whitefish Pre (1b)	Whitefish Post (1b)	Whitefish % Change (approx)	Walleye Pre (1b)	Walleye Post (1b)	Walleye % Change (approx)	Total Yield Pre (1b)	Total Yield Post (1b)	Total Yield % Change (approx)
1 2 3 7	233,000	220,000	210,000	- 5	33,000	31,500	- 5	253,000	241,500	- 5
4	155,000	680,000	540,000	-20	70,000	56,000	-20	750,000	596,000	-20
6	29,000	-	35,000	-	5,000	5,500	+10	5,000	40,500	+800
Total	417,000	900,000	785,000	-13	108,000	93,000	-14	1,008,000	878,000	-13

MITIGATION

Major recommendations are given below.

1. The above impact assessment has been based on the assumption that the mean annual discharge at Missi Rapids will be approximately 6,000 cfs. Lake productivity will decline under this flow regime, but the consequences will not be drastic. The interim license which Manitoba Hydro holds would allow a mean annual discharge of 1,000 cfs in dry years with high power demand. This greatly reduced flow would be incompatible with maintaining the basic productivity of the lake at an acceptable level. It is recommended that a mean annual discharge of 5,000 cfs at Missi Rapids be guaranteed. To be most beneficial, this flow should follow the natural variation, i.e. high in late spring and early summer and low in winter.

2. An extensive clearing program should be initiated with the major goals being to:

   a) prepare possible spawning sites for whitefish among the islands immediately adjacent to Missi Rapids;
   b) insure that major tributaries used by walleyes for spawning are kept free from debris to allow for unimpeded passage of walleye upstream;
   c) create safe landing sites at regular intervals along the new shoreline so that fishermen will not be stranded offshore in inclement weather;
   d) clear all shoreline that is to be inundated in areas immediately

adjacent to settlements and fish camps.

This clearing recommendation (a) has already been communicated (see attached letter) to Manitoba Hydro and the amounts of land to be cleared are under negotiation.

3. In view of the potential of region 5 for producing floating debris, it is recommended that the feasibility of a boom across the channel past Sand Point be investigated. Local fishermen should be consulted on the desirability of such a boom so that they may weigh the advantages of reduced floating debris on the present fishing grounds against reduced access to region 5 which appears to be reasonably productive, yet unexploited, fishing area.

4. The present study has been confronted with numerous questions for which past experience on reservoirs in other geographic regions has been inadequate to allow suitable answers. In order that future assessments might be more useful and that operation of the present development might be refined to minimize detrimental impacts, it is recommended that a program to monitor Southern Indian Lake and its fishery be maintained following development. The goals of this program would be to determine:

a) what effect the reduction of flow will have on regions 3 and 4;

b) what effect the increased flow of the Churchill will have on South Bay and the new downstream reservoir;

c) what effect inundation has on the limnology of a high northern latitude lake.

With the extensive and expensive pre-development surveys completed, an adequate monitoring program could be operated over a period of years at a reasonable cost. Results of such a program would be useful and beneficial to assessors, developers, and study boards as it could eliminate some of the "mystification" of hydroelectric developments and allow future discourses to be more rational and less emotional.

December 7, [illegible]

Your file Votre référence

Our file Notre référence

738-3-7-4

Mr. C. Goodwin
Manitoba Hydro
820 Taylor Avenue
WINNIPEG, Manitoba

Dear Mr. Goodwin:

Re: Clearing Areas for Whitefish Spawning on Southern Indian Lake

At the meeting held in the Churchill Nelson Basin study office on September 19, Manitoba Hydro offered to undertake a trial clearing operation at selected sites on Southern Indian Lake to enhance the prospects of protection of whitefish spawning grounds.

It was agreed that representatives of Fisheries Service would visit the project area and select a suitable group of sites for clearing this winter. These sites were to be near Missi Falls in the area identified in the fisheries limnology component of the Study as a major whitefish spawning area.

It was suggested at the above meeting that the total area for which pre clearing would be of benefit to the whitefish spawning grounds comprises about 1000 acres. As understood by us, the trial clearing operation this winter could cover up to 100 acres and would have the following objectives:

1. To contribute to the pre clearing of spawning areas for whitefish, and incidentally other purposes such as safety of navigation.
2. To enable Fisheries Service to better appraise the likely value and appropriate degree of treatment (type of clearing) with respect to possible extension of the pre clearing program to the remainder of the 1000 acres mentioned above.
3. To enable Manitoba Hydro to accurately assess the cost of an extensive pre clearing operation to the standard requested by Fisheries Service.

Subsequently, on October 18 and 19, Mr. J. M. Millen and Mr. W. Baxter, Fisheries and Marine Service, visited Missi Falls and inspected most of the islands in the area. A selection has been made of suitable sites and is shown in the table and map attached.

Freshwater Institute
501 University Crescent
Winnipeg, Manitoba
R3T 2N6

... /2

Institut des eaux douces
501 University Crescent
Winnipeg, (Manitoba)
R3T 2N6

F4-1000 (4/73)

In preparing the specification for this clearing the objectives should be kept in mind. We determined by our site visit that there are very few islands which have such a low elevation that they will be submerged entirely at the new water level. Therefore, in general the clearing will comprise a shoreline strip. The result we are aiming for, for whitefish spawning, is a clean rocky bottom in the depths ranging from five to fifteen feet under the raised lake levels. In addition it is essential for whitefish spawning success that the new shoreline shall rapidly reach a sufficiently stable form. Stability must be such that the whitefish eggs are not subject to smothering by silt or fine sand, from the time of spawning in late September until their hatching in March. The pre clearing is intended to aid in this process partly by exposing the limited areas of rocky foreshore on islands but mainly by promoting rapid stabilization of new shorelines. Island sites have been selected because they will be better isolated from the massive shoreline stabilization processes expected in some main shore areas.

Hence it is suggested:

1. That rocky slopes which would require hand clearing be cleared only if the gradient is flatter than say one in four, as the contributed area of abrupt bluffs and steep slopes would probably not contribute greatly to whitefish spawning area.

2. Where machine clearing is possible that clearing and piling should include as much grubbing as practicable and that all detritus should be burnt. Consideration should be given to arranging a final summer clean up and burn.

3. Many islands have foreshore areas containing sparse stands of Willows and alders. If these areas cannot be grubbed by machine they could be left as they are. The alternative of hand cutting probably will not contribute greatly to establishment of spawning areas.

4. It would be desirable to keep account of costs for different areas so that the relative costs of different types of clearing could be compared with the expected benefits. Fisheries personnel will be prepared to make an inspection visit next summer and participate in the evaluation of the clearing work. A decision could then be made on the extension of this clearing to the remainder of the identified whitefish spawning area.

... /3

If we could be of any more assistance to you in formulating clearing programs, please contact us.

Yours truly,

Att

J. M. Millen
Head, Resource Impact Division
Resource Management Branch
Central Region

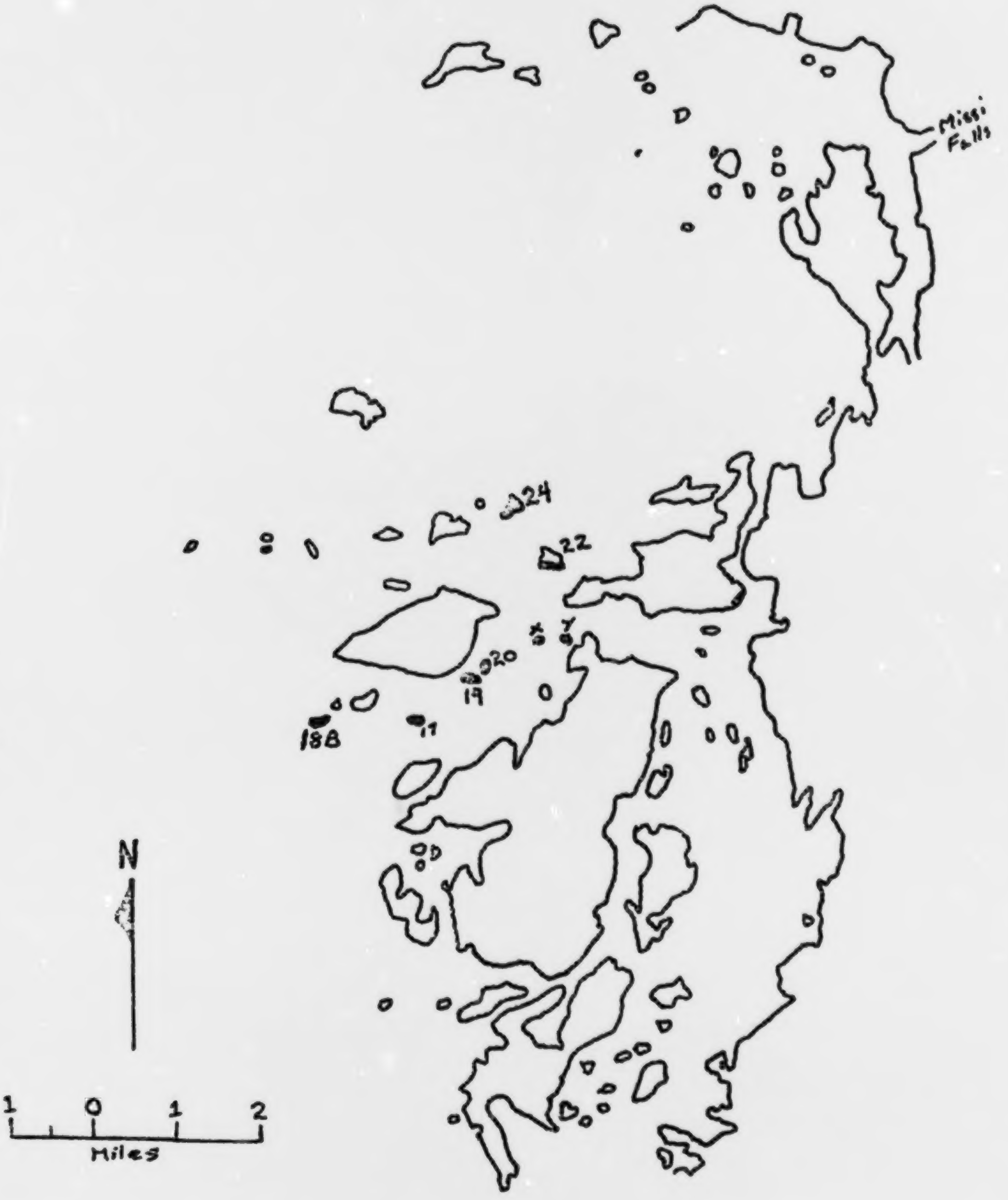
cc: Mrs. Betty Nowicki
Study Office
Manitoba Hydro

B. Hecky, Acting Program Leader
Churchill-Nelson S.I.L. Studies
Limnology-Eutrophication Section, Fisheries and Marine Service

H. Ayles
Churchill-Nelson S.I.L. Studies
Limnology-Eutrophication Section, Fisheries and Marine Service

Summary of the islands picked for clearing on Southern Indian Lake during the October 18 and 19 visit to Missi Falls. For the exac location of the islands see the map.

Island Number	Part to be Cleared	estimated Length x Width	Area (Acres)
17	all	4000' x 100'	10
18B	all	4000' x 100'	10
19	all	-	15
20	all	-	10
22	S. shore only	2000' x 100'	5
24	Strip on E. side	2000' x 100'	5
X	all		10
Y	All except strip N.W. shore		10
			75 acres


Missi Falls
24
22
7
20
19
188
17
N
1 0 1 2
Miles

Southern Indian Lake - Missi Falls Area
- Whitefish Spawning Areas to be Cleared
in Black. (No. correspond to table).

APPENDIX 5 - VOL. 1 - B.

THE MORPHOMETRY OF SOUTHERN INDIAN LAK
PRESENT CONDITIONS AND IMPLICATIONS
OF HYDROELECTRIC DEVELOPMENT

THE MORPHOMETRY OF SOUTHERN INDIAN LAKE: PRESENT CONDITIONS AND IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

by

T. R. CLEUGH, H. AYLES and W. BAXTER
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
February, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

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ACKNOWLEDGMENTS

We express our thanks to M. Kreger for field assistance and to T. Hallas, R. Brako, S. Brown, L. Siemieniuk and S. Zettler for preparation of tables and bathymetric map.

PRESENT CONDITIONS

Morphometric parameters (e.g. lake volume, area, depth) are of primary concern in any aquatic habitat. They can influence the biological productivity of the lake and are of importance to the fish harvest potential.

Southern Indian Lake on the Churchill River, is located approximately 480 miles north of Winnipeg, Manitoba at 98°00' - 99°30' W, 56°30' - 57°45'N at an historic mean altitude of 836 feet (historic range is 831.9 - 849.5 feet) above mean sea level. The mean date for freeze-over of Southern Indian Lake is November 1, and for breakup, May 25. The yearly mean daily temperature is 24°F and the mean annual precipitation is between 14 and 16 inches.

Although the headwaters of the Churchill River are on the physiographic region known as the Interior Plains, Southern Indian Lake and its immediate drainage basin are situated entirely on the Precambrian Shield (dominant surface material is primarily glacio-lacustrine clay).

The lake is accessible by airplane year round and during the winter, by winter roads. South Indian Lake post has a population of approximately 700, who are dependent on commercial fishing for their livelihood.

The bathymetric map (see inside of back cover) of Southern Indian Lake was prepared from sonar transects between shore stations located on aerial mosaics. A Furuno Model FG-200 Mark II (200 KC transducer) was calibrated using a sounding line. The lake outline was prepared from aerial mosaics adjusted to two inches to the mile. The original aerial photos were taken from 9,600' altitude. The horizontal control was achieved using a range finder between shore stations located on the mosaics. Some error is inherent in these techniques, especially in the adjustment of the aerial photos to the mosaics. Replicate sonar transects were made and several horizontal control measurements were obtained within each region. A total of 500 major transects were obtained from the entire lake. The analyses are reported in Tables 1-3.

Because of the size and complexity of Southern Indian Lake, it was divided into seven regions (Figure 1). Boundaries were placed at natural channel constrictions which separate the lake into individual basins. General morphometric parameters for Southern Indian Lake (Tables 1, 2 and 3) were obtained in the following manner. Areas of land and water were calculated using a polar planimeter and shoreline lengths with a map measurer. Volumes of contour delimited segments were calculated by the equation (1) below, and the basin volume determined by summation.

$$(1) \qquad V = \frac{h}{3}(a_1 + a_2 + \sqrt{a_1 \cdot a_2}) \; \ldots \; \text{(Hutchinson 1957)}$$

Where V = volume in cubic meters

h = depth between contours in meters

a_1= area of contour 1 in square meters

a_2= area of contour 2 in square meters

Shoreline development factor was calculated using the formula (2):

$$(2) \qquad SDF = \frac{S}{2\sqrt{\pi A}} \qquad \text{(Hutchinson 1957)}$$

Where SDF = shoreline development factor

S = length of shoreline in miles

A = area of lake in square miles

A shoreline development of 12.41 (Southern Indian Lake) reflects the intricate outline. The number of islands (reefs were not recorded) were taken directly from aerial mosaics, shoreline insulosity (% area of islands in relation to total area of lake) was determined using the calculated figures, and mean depth was determined using total volume and surface area of water. Maximum depths were taken from the contour map but tend to be misleading, e.g. maximum depth of 37 meters occurs only in one small depression.

The mean rate of flow of water at the outlet of Southern Indian Lake (Missi Falls) is 35,400 cfs with a minimum and maximum flow of 17,000 cfs and 65,000 cfs, respectively (Manitoba Water Resources 1973). For the calculation of exchange time, complete mixing of the water in each region was assumed; however, data presented later in this report indicate that complete mixing does not occur and likely the river water moves through regions 0-4 more quickly than has been calculated. The rate of flow through the main lake regions (regions 0-4) was taken to be the mean annual flow of water from the Churchill and Barrington Rivers (Manitoba Water Resources 1973). The rates of flow for regions 5, 6 and 7 were calculated using the size of the drainage basin and the constant 0.675 (Manitoba Water Resources 1973). The contribution from the drainage basins of regions 0-4 was not considered to be large enough relative to the river flow to include in the calculations. In several regions the large number of islands (e.g. region 2) and the large shoreline length (e.g. region 7) have a major inhibiting effect on the circulation and flow of water in Southern Indian Lake. A comparison of morphometric parameters of four lakes on the Churchill River (Rawson 1960) with Southern Indian and Opachuanau Lakes appears in Table 4.

IMPACT

Table 5 estimates the morphometric parameters of Southern Indian and Opachuanau Lakes under conditions proposed by Manitoba Hydro. For the purpose of these estimates it was assumed that the new water level would be at 850 feet. Flow through regions 0, 1, 5 and 7 was taken to be unchanged from pre-impoundment conditions. Region 6 was considered to have the full diversion flow plus a drainage estimate from local runoff water. Regions 3 and 4 were considered to have a mean residual flow from the Churchill River (3,700 cfs,Cleugh 1973) as well as flow from drainage of local streams. Because of the location of region 2, it was assumed that one-half of this region received the full flow of the Churchill (31,400 cfs) and the remaining received the residual flow (3,700 cfs).

Under new conditions changes in rate of flow through regions 3 and 4 will be extreme. Flows of over 31,000 cfs are predicted for more than 25% of the time in June, and may reach 65,000 cfs in very wet years. During periods of drawdown , February-May, flows may be negative (from region 4 to 3) all of which can affect water exchange, shoreline stabilization and sedimentation within the altered lake.

Though the relative amount of land to be flooded is not great (202 sq miles or 22% of the new surface area) its effect may be obvious on the total lake. Quantities of organic debris from flooded land will be added to the lake. Areas of flooded peat bogs and swamp could be a source of floating islands. A high percentage of the new shoreline, created by the increase in water level, will be of alluvial clay on permafrost (Jean Thie, pers. comm.). The presence of permafrost will prolong shoreline stabilization and cause extensive slumping. Shoreline erosion will introduce quantities of suspended clay into lake water for currents to distribute. Patterns of distribution and quantities of sediment contribution can only be theoretical at this point.

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PERSONAL COMMUNICATIONS

Thie, J Forest Section, Resources Projects. Department of Mines. Resources and Environmental Management, Winnipeg, Manitoba.

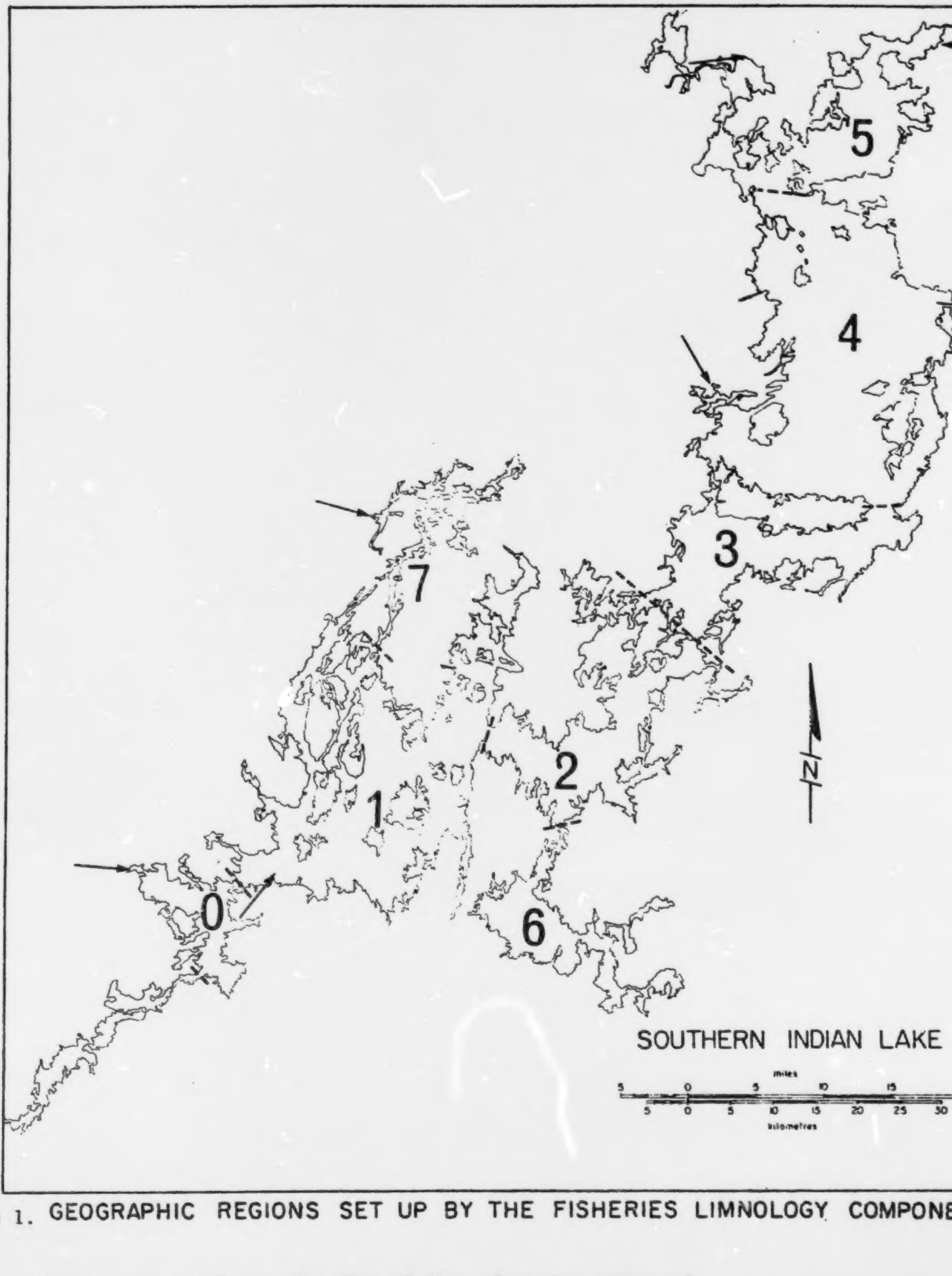
5
4
3
7
2
1
0
6
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15
5 0 5 10 15 20 25 30
kilometres

Figure 1. GEOGRAPHIC REGIONS SET UP BY THE FISHERIES LIMNOLOGY COMPON

(note: arrows indicate direction of flow of major streams)

Table 1. General morphometric parameters of seven regions of Southern Indian Lake and Opachuanau Lake.

	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5	REGION 6	REGION 7	TOTAL EXCLUDING REGION 0	REGION 0 OPACHUANAU LAKE
Total area[a]									
sq. meters x 10^6 (sq. miles)	646.7 (249.7)	285.8 (110.4)	215.2 (83.1)	713.1 (275.3)	218.9 (84.5)	124.5 (48.1)	49.2 (19.0)	2253.4 (870.1)	79.6 (30.8)
Maximum depth									
meters (feet)	31.5 (103.3)	37.0 (121.4)	27.9 (91.5)	32.5 (106.6)	30.5 (100.1)	11.5 (37.7)	16.0 (52.5)	37.0 (121.4)	26.0 (85.3)
Mean depth									
meters (feet)	8.5 (27.9)	8.1 (26.6)	9.3 (30.5)	12.7 (41.7)	5.3 (17.4)	3.9 (12.8)	4.6 (15.1)	9.2 (30.2)	5.3 (17.4)
Mean depth ÷ Maximum depth	0.27	0.22	0.33	0.39	0.17	0.34	0.29	0.25	0.20
Volume									
cu. meters x 10^9 (acre-feet x 10^6)	4.01 (3.25)	1.80 (1.46)	1.85 (1.50)	7.93 (6.43)	1.12 (0.91)	0.47 (0.38)	0.21 (0.17)	17.39 (14.10)	0.41 (0.33)
Flow cu. cm/sec. x 10^6 (cfs.)	889.1 (31400)	889.1 (31400)	889.1 (31400)	889.1 (31400)	25.7 (909)[b]	4.7 (167)	19.4 (685)	1002.4 (35400)	889.1 (31400)
Exchange time									
days years	52.2	23.5	24.1	103.2	503.8 (1.38)	1143.9 (3.13)	124.1	201.6	5.3

a. total area of water and islands.

b. includes Waddie and Muskwesi Rivers

Table 2. Areas of contours and volumes of seven regions of Southern Indian Lake and Opachuanau

	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5	REGION 6	REGION 7	TOTAL EXCLUDING REGION 0	REGION 0 OPACHUANAU LAKE
Water area 0 m contour									
sq. meters x 10^6 (sq miles)	474.6 (183.2)	223.3 (86.2)	199.8 (77.1)	626.5 (241.9)	210.6 (81.3)	119.5 (46.2)	45.5 (17.6)	1899.8 (733.5)	77.3 (29.8)
5 m contour area									
sq. meters x 10^6 (sq. miles)	315.8 (121.9)	133.7 (51.6)	142.9 (55.2)	485.7 (187.5)	79.4 (30.7)	42.2 (16.3)	15.4 (6.0)	1215.1 (469.2)	27.2 (10.5)
10 m contour area									
sq. meters x 10^6 (sq. miles)	197.3 (76.2)	80.5 (31.1)	92.5 (35.7)	382.1 (147.5)	35.0 (13.5)	0.5 (0.2)	6.0 (2.3)	793.9 (306.5)	11.3 (4.4)
15 m contour area									
sq. meters x 10^6 (sq. miles)	60.3 (23.3)	31.4 (12.1)	34.5 (13.3)	282.3 (109.0)	8.9 (3.4)	--	0.4 (0.2)	417.8 (161.3)	5.2 (2.0)
20 m contour area									
sq. meters x 10^6 (sq. miles)	6.8 (2.6)	9.5 (3.7)	5.9 (2.3)	136.1 (52.5)	3.2 (1.2)	--	--	161.5 (62.3)	2.4 (0.9)
25 m contour area									
sq. meters x 10^6 (sq. miles)	0.8 (0.3)	0.7 (0.3)	0.7 (0.3)	7.7 (3.0)	0.8 (0.3)	--	--	10.7 (4.2)	0.1 (<.1)
30 m contour area									
sq. meters x 10^6 (sq. miles)	<.1 (<.1)	0.2 (0.1)	--	0.5 (0.2)	0.2 (0.1)	--	--	0.9 (0.4)	--
Volume									
cu. meters x 10^9 (acre-feet) x 10^6	4.01 (3.25)	1.80 (1.46)	1.85 (1.50)	7.93 (6.43)	1.12 (0.91)	0.47 (0.38)	0.21 (0.17)	17.39 (14.10)	0.41 (0.33)

Table 3. Areas and shoreline lengths of seven regions of Southern Indian Lake and Opachuanau Lake.

	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5	REGION 6	REGION 7	TOTAL EXCLUDING REGION 0	REGION 0 OPACHUANAU LAKE
Total area									
sq. meters x 10^6 (sq. miles)	646.7 (249.7)	285.8 (110.4)	215.2 (83.1)	713.1 (275.3)	218.9 (84.5)	124.5 (48.1)	49.2 (19.0)	2253.4 (870.1)	79.6 (30.8)
No. of islands	337	241	133	318	79	80	71	1309	84
Island area									
sq. meters (sq. miles)	172.1 (66.5)	62.5 (24.2)	15.4 (5.9)	86.6 (33.4)	8.3 (3.2)	5.0 (1.9)	3.6 (1.4)	353.6 (136.5)	2.4 (0.9)
Insulosity %	26.6	21.8	7.1	12.1	3.7	4.0	7.3	15.6	2.9
Shoreline length total									
kilometers (miles)	1066.7 (662.8)	615.3 (382.4)	334.0 (207.6)	571.7 (355.2)	314.4 (195.4)	280.0 (174.0)	327.5 (203.5)	3509.8 (2180.9)	155.0 (96.3)
Lake outline									
kilometers (miles)	437.5 (271.8)	320.5 (199.2)	217.5 (135.2)	221.5 (137.6)	234.0 (145.4)	228.5 (142.2)	258.0 (160.3)	1917.5 (1191.5)	141.5 (87.9)
Islands									
kilometers (miles)	629.2 (391.0)	294.8 (183.2)	116.5 (72.4)	350.2 (217.6)	80.4 (50.0)	51.5 (32.0)	69.5 (43.2)	1592.3 (989.4)	13.5 (8.4)
Shoreline development excluding islands			-	-	-	-	-	12.4	4.5
Including islands	-	-	-	-	-	-	-	22.7	5.0

Table 4. A morphometric comparison of Southern Indian and Opachuanau Lakes with four lakes in the Churchill River system (after Rawson 1960).

	WOLLASTON	REINDEER	LA RONGE	ILE ALA CROSS	SOUTH INDIAN LAKE	OPACHUANAU
Water area						
sq. kilometers (sq. miles)	2062 (796)	5569 (2150)	1178 (455)	446 (172)	1900 (734)	77 (30)
Mean depth						
meters (feet)	20.6 (67.6)	17+ (55.7)	12.7 (41.6)	8.2 (26.9)	9.2 (30.2)	5.3 (17.4)
Maximum depth						
meters (feet)	97 (318)	215 (705)	38 (124)	27 (88.6)	37.0 (121.4)	26.0 (85.3)
Shore length (total)						
kilometers (miles)	2885 (1790)	4370 (2710)	1780 (1105)	617 (382)	3509.8 (2180.9)	155.0 (96.3)
Shore development	7.5	9.0	6.8	7.6	12.4	4.5
Shore development with isles	14.7	16.5	11.6	8.2	22.7	5.0
No. of islands	370	2500	1160	59	1309	84
Area of islands						
sq. kilometers (sq. miles)	513 (198)	961 (371)	114 (44)	6.0 (2.3)	353 (136)	2.3 (0.9)
Islands % of total area	19.9	14.5	8.8	1.3	15.6	2.9

Table 4 (cont.)

Altitude						
meters (feet)	397 (1300)	351 (1150)	366 (1198)	421 (1382)	(836)	(836)
Drainage area						
sq. kilometers (sq. miles)	23310 (9000)	64750 (25000)	14763 (5700)	77700 (30000)	-	-
Flushing						
years	14	11	19	0.75	0.55	0.014

Table 5. Areas of contours, volumes, mean depths and exchange times of seven regions of Southern Indian Lake and Opachuanau Lake under impoundment conditions.

WATER AREA	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5	REGION 6	REGION 7	TOTAL EXCLUDING REGION 0	REGION 0 OPACHUANAU LAKE
Om contour									
sq. meters x 10^6	535.4	296.1	267.9	775.9	337.8	145.4	64.9	2423.4	96.7
(sq. miles)	(206.7)	(114.3)	(103.4)	(299.6)	(130.4)	(56.1)	(25.1)	(935.6)	(37.3)
3.5 m contour									
sq. meters x 10^6	474.6	223.3	199.8	626.5	210.6	119.5	45.5	1899.8	77.3
(sq. miles)	(183.3)	(86.2)	(77.1)	(241.9)	(81.3)	(46.1)	(17.6)	(733.5)	(29.8)
8.5 m contour									
sq. meters x 10^6	315.8	133.7	142.9	485.7	79.4	42.2	15.4	1215.1	27.2
(sq. miles)	(121.9)	(51.6)	(55.2)	(187.5)	(30.7)	(16.3)	(6.0)	(469.2)	(10.5)
13.5 m contour									
sq. meters x 10^6	197.3	80.5	92.5	382.1	35.0	0.5	6.0	793.9	11.3
(sq. miles)	(76.2)	(31.1)	(35.7)	(147.5)	(13.5)	(0.2)	(2.3)	(306.5)	(4.4)
18.5 m contour									
sq. meters x 10^6	60.3	31.4	34.5	282.3	8.9	-	0.4	417.8	5.2
(sq. miles)	(23.3)	(12.1)	(13.3)	(109.0)	(3.4)		(0.2)	(161.3)	(2.0)
23.5 m contour									
sq. meters x 10^6	6.8	9.5	5.9	136.1	3.2	-	-	161.5	2.4
(sq. miles)	(2.6)	(3.7)	(2.3)	(52.5)	(1.2)			(62.3)	(0.9)
28.5 m contour									
sq. meters x 10^6	0.8	0.7	0.7	7.7	0.8	-	-	10.7	0.1
(sq. miles)	(0.3)	(0.3)	(0.3)	(3.0)	(0.3)			(4.2)	(<0.1)
33.5 m contour									
sq. meters x 10^6	0.1	0.2	-	0.5	0.2	-	-	1.0	-
(sq. miles)	(<0.1)	(0.1)		(0.2)	(0.1)			(0.4)	

Table 5 (cont.)

WATER AREA	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5	REGION 6	REGION 7	TOTAL EXCLUDING REGION 0	REGION 0 OPACHUANAU LAKE
Total area									
sq. meters x 10^6 (sq. miles)	667.5 (257.7)	349.4 (134.9)	306.2 (118.2)	870.0 (335.9)	369.4 (142.6)	149.9 (57.9)	68.2 (26.3)	2780.6 (1073.6)	103.0 (39.8)
Island area									
sq. meters x 10^6 (sq. miles)	132.1 (51.0)	53.3 (20.6)	38.4 (14.8)	94.1 (36.3)	31.6 (12.2)	4.6 (1.8)	3.3 (1.3)	357.4 (138.0)	6.5 (2.5)
Water area									
sq. meters x 10^6 (sq. miles)	535.4 (206.7)	296.1 (114.3)	267.9 (103.4)	775.9 (299.6)	337.8 (130.4)	145.6 (56.2)	64.9 (25.1)	2423.4 (935.7)	96.6 (37.3)
Volume									
cu. meters x 10^9 (acre-feet x 10^6)	5.75 (4.66)	2.71 (2.20)	2.66 (2.15)	10.37 (8.41)	2.07 (1.67)	0.93 (0.75)	0.40 (0.33)	24.89 (20.17)	0.71 (0.58)
Mean depth									
meters (feet)	10.7 (35.1)	9.2 (30.2)	9.9 (32.5)	13.4 (43.9)	6.1 (20.0)	6.4 (21.0)	6.2 (20.3)	10.3 (33.8)	7.4 (24.3)
Shoreline length total									
kilometers (miles)	1029.6 (639.8)	512.3 (318.4)	281.2 (174.7)	756.9 (470.3)	551.2 (342.5)	255.5 (158.7)	208.0 (129.3)	3594.7 (2233.7)	193.5 (117.8)
Lake outline									
kilometers (miles)	379.6 (235.9)	241.3 (150.0)	147.3 (91.5)	339.1 (210.7)	360.7 (224.1)	210.4 (130.7)	130.8 (81.3)	1809.2 (1124.2)	163.9 (101.8)
Island outline									
kilometers (miles)	650.0 (403.9)	271.0 (168.4)	133.9 (83.2)	417.8 (259.6)	190.5 (118.4)	45.1 (28.0)	77.2 (48.0)	1785.5 (1109.5)	29.6 (16.0)

Table 5 cont.

WATER AREA	REGION 1	REGION 2	REGION 3	REGION 4	REGION 5	REGION 6	REGION 7	TOTAL EXCLUDING REGION 0	REGION 0 OPACHUANAU LAKE
Flow									
cu cm/sec x 10^6	889.1	496.8	107.0	110.8	25.7	893.9	19.4	-	889.1
(cfs)	(31,400)	(17,544)	(3,779)	(3,912)	(909)	(31,567)	(685)	-	(31,400)
Exchange time									
Days	74.9	63.1*	287.7	1083.5	930.8	12.0	238.7	-	9.2
Years	0.2	0.2	0.8	3.0	2.54	0.03	0.7	-	0.03
Shoreline development factor									
excluding islands	-	-	-	-	-	-	-	10.4	4.7
including islands	-	-	-	-	-	-	-	20.5	5.4

* Assuming one half of region 2 receives the full Churchill River flow, 31,400 cfs and one half receives 3,800 cfs the exchange time would be 17 days for the upper half and 147 days for the lower half of region 2.

APPENDIX 5 - VOL. 1 - C.

THE HYDROGRAPHY OF SOUTHERN INDIAN LAKE: PRESENT CONDITIONS AND IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

THE HYDROGRAPHY OF SOUTHERN INDIAN LAKE: PRESENT CONDITIONS AND IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

by

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Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
August, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

ABSTRACT

The chemical limnology of Southern Indian Lake was investigated during 1972-73. Six stations in the lake, the five major inflows, and the outlet were monitored at triweekly intervals through the ice-free season and at longer intervals through the winter. Vertical profiles of temperature, oxygen and chemical constituents indicated that the lake has no significant stratification at any season. The lake is relatively untransparent with Secchi disc readings ranging from 1-2.5 m. The northern end of the lake which is most remote from the Churchill River had the most transparent water. South Bay, the basin north of Sand Point, and the bays off the northern shore of the lake had chemical compositions distinct from those lake regions on the main axis of flow of the Churchill River. Summer heat budgets indicated that the Churchill River is probably an important heat source in the immediate vicinity of its entry to the lake, but it cannot be important in determining the time of ice-out for the northern portion (north of Long Point) of the lake. The river is, however, an extremely important nutrient source to all regions of the lake which receive significant flow. Annual phosphorus loading for the whole lake is 0.35 gms/m^2, but the loading is inequitably distributed. South Bay and the region north of Sand Point have much lower loading rates while the main lake regions receiving full Churchill River flow receive 0.5 gms/m^2. Phosphorus retention is only 12% of input which indicates inefficient utilization or very efficient regeneration of nutrients by microbial activity.

After diversion local stream runoff will exert a much greater influence on the northern portion of the lake. The major ion composition will change and nutrient loading will decline in proportion to the decline in discharge at Missi Rapids. Impoundment will release nutients from inundated vegetation and soils. But this new loading will only partially offset the loss of the Churchill, and its significance will decline over time. Shoreline stabilization in the clay overburden will substantially increase turbidity inshore and, to a lesser extent, offshore further decreasing light transmission. Isolated bays with extensive flooding will have reduced oxygen concentrations because of microbial decomposition of inundated organic materials.

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INTRODUCTION

Water quality is fundamental to the productivity of natural waters. Recognition of this required that a detailed hydrographic survey of Southern Indian Lake be undertaken as part of the Fisheries-Limnology component of the Lake Winnipeg, Churchill and Nelson Rivers Study. This report characterizes the water chemistry of Southern Indian Lake during 1 June 1972 to 28 March 1973. On the basis of these short-term observations, the report also attempts to foresee and where possible, quantitatively estimate probable changes in chemical parameters because of impoundment and diversion. Although the survey attempted broad coverage, the greatest effort in evaluating impact assessment has necessarily centered on those parameters, especially nutrients, which are most likely to alter the basic productivity of Southern Indian Lake.

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GEOGRAPHY AND CLIMATE

The Churchill River begins northeast of Edmonton, Alberta and flows eastward for over 700 miles to Hudson Bay. It drains a large (115,000 square miles) and heterogeneous basin consisting of Cretaceous sediments in Alberta and western Saskatchewan, Precambrian Shield in eastern Saskatchewan and Manitoba and Ordovician limestone near Hudson Bay.

Southern Indian Lake is located in northern Manitoba 250 miles southeast of Hudson Bay on the Churchill River. The lake is situated on the Precambrian Shield (98°10' - 99°30'W by 56°45' - 57°40'N). The Shield in Manitoba consists of rounded granite outcrops mantled by varying depths of glacial drift and lacustrine clays deposited by glacial Lake Agassiz (Bell, 1971; Bryson and Wendland, 1967; Can. Dept. Energy, 1968; Elson, 1967; Prest, 1969).

The Southern Indian Lake area has a mean annual temperature of approximately 25°F (-4°C). The mean annual precipitation averages 15-17 inches (38-43 cm), 1/3 of which falls as snow (Can. D.O.T., 1957; D.O.T., 1967-1970; D.O.T., 1969; Thomas, 1953).

2.2.1. HYDROLOGY

The Churchill River, at Opachuanau Rapids, has an annual mean flow of 31,400 cfs, or 92% of the total flow at Missi Rapids (Man. Hydro, 1970). The mean annual discharge at Missi Rapids is 35,400 cfs, the difference in flows coming as runoff from the local streams and precipitation, 15"-17"/annum, less evaporation, 12"/annum (D.O.T. Met. Branch 1967-70), on the lake's surface.

Total flow estimates for Southern Indian Lake are given in Table 2.2.1.1. Stream flows were based on drainage areas converted to cubic feet per second using a long-range constant [0.675] (Manitoba Water Resources). Ninety percent of all the streams flowing into Southern Indian Lake were chemically sampled and the mean discharge estimated. The mean discharge and location for each stream sampled is listed in Appendix I, Table 1. Present local stream flow into Southern Indian Lake is 8% of the total flow at Missi. After diversion the hydrological regime above Region 2 (Figure 2.2.1.1.) will remain similar to the present situation; but below this region, local streams will contribute approximately 37% of the total discharge at Missi. Sixty-three percent of the Missi discharge will originate above Region 2 of which 97% will be from the Churchill River. After diversion only 7% of the present flow from the Churchill River will pass through Missi Rapids, but this greatly reduced discharge will still be a significant fraction of the total flow into Regions 3 and 4. Pre- and post-impoundment mean monthly flows at Missi are estimated in Table 2.2.1.1; drawdown will occur between

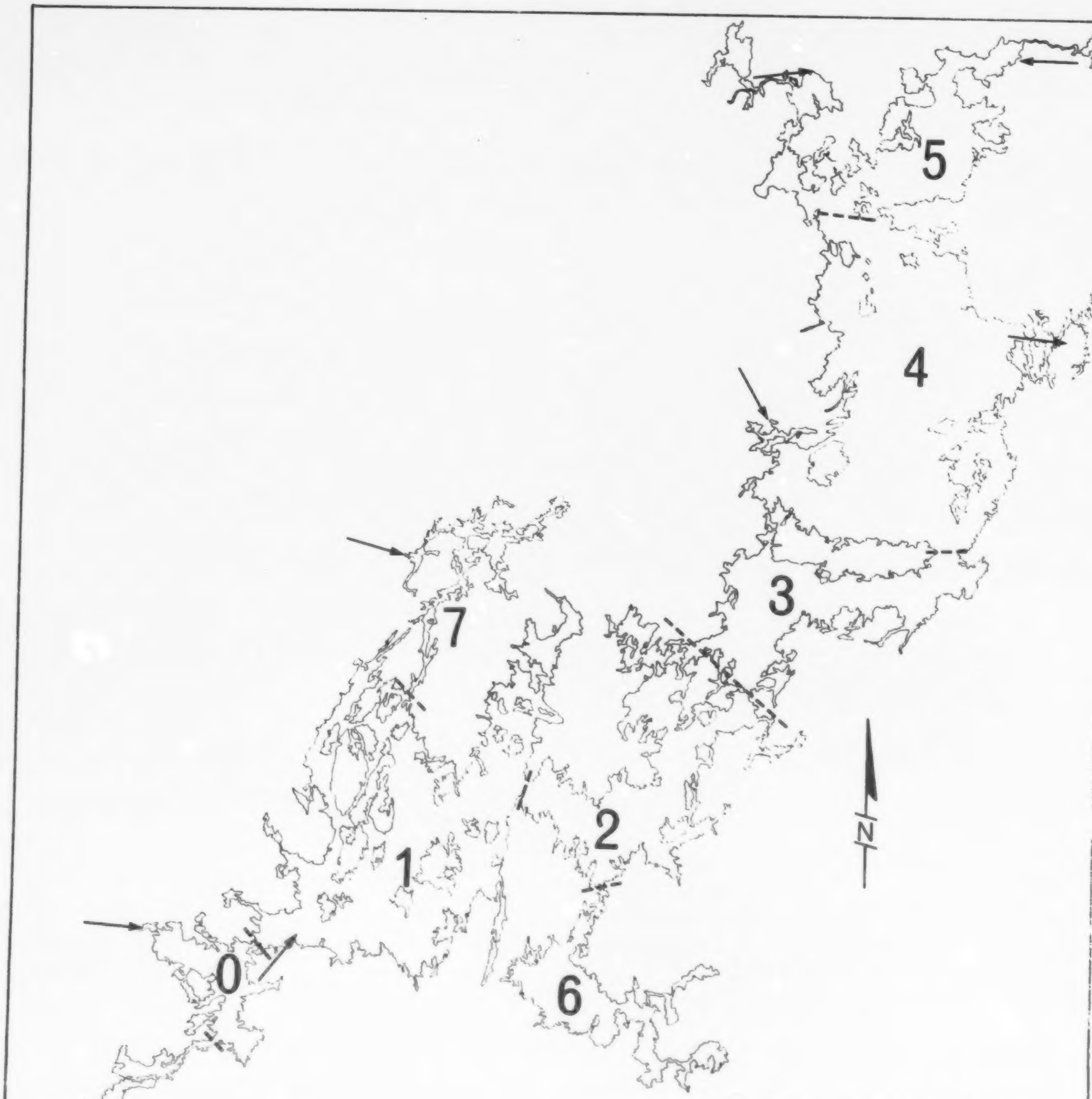
February and May when low winter Churchill River flows will be below the desired discharge at the diversion canal. The Water Resources Branch of the Manitoba Department of Mines, Resources and Environmental Management estimates this annual drawdown will be approximately two feet.

The distribution of zooplankton in Southern Indian Lake (Patalas, 1974) implies that there are several discrete water masses in the lake, and inflowing water is not equally distributed over the lake. Rather a distinct river plume exists along the southeastern side of the basin during passage. Southern Indian Lake stations 09, 10, 20, 30 and 40 to Missi Rapids are located in or near this Churchill River plume. This would imply that the turnover time is much lower for this part of the lake than the times for each region estimated in Cleugh, Ayles and Baxter (1974).

Turnover times can be more directly estimated if suitable chemical tracers of water masses can be identified. With such tracers the time differential between similar changes in concentrations at different stations serves as a direct estimate of water renewal. In Southern Indian Lake two such water markers, sodium and silicon, were observed. A comparison of the chemical concentrations of these two species indicates a seasonal oscillation observed at all stations in the Churchill River plume. Other elements were not as suitable because their biogeochemical cycles were more complex involving precipitation, dissolution, ion exchange and biological reactions. By comparing the timing of minimum sodium concentrations at the main stations (Table 2.2.1.4.), it appears that approximately 70 days are required for the low sodium water present at station 10 on July 10 to be transported to station 40. From this estimate the turnover time for the whole Churchill River plume between Opachuanau and Missi Rapids is on the order of 100 days or one half the time calculated in, Cleugh, Ayles and Baxter (1974), where complete mixing over the entire lake volume was assumed. This low sodium concentration occurs as a result of the spring thaw when the melt water dilutes runoff. Dilution of other major cations is apparently offset by dissolution from and/or cation exchange with solid phases. Anion concentrations are too low to be estimated with any precision, but electrical conductivity, which is a measure of total ionic activity, shows a similar cyclic behavior with a periodicity comparable to sodium (Appendix II).

The silicon oscillation has an entirely different causation. Silicon is a biologically active ion, and a biological modification of the silica cycle occurs in natural waters when inhabited by diatoms. Southern Indian Lake in 1972-73, had its highest silicon concentrations (approximately 1.5 mg/l) in the winter months when algal activity was low. This concentration decreased from late March to early June by 50-80% through the entire Churchill River plume. This decrease in silicon concentration is attributable to a large diatom bloom in early spring (Hecky, 1974). After the bloom terminates, silicon concentration begins to approach the concentration of the Churchill River which remains relatively constant from June 21 to September 12, 1972. The time required for the lake stations to be affected by the river water is similar to that estimated for sodium. After August 21 the response of the lower lake is complicated by a second increase in diatoms (Hecky,

1974) which again lowers silicon concentrations in the lower lake. However, by December 10, station 40 has a concentration of 1.3 mg/l which is nearly its seasonal maximum. Only the Churchill River and station 10 had concentrations this high in October, indicating that between October 3 and December 10 this water had travelled nearly the length of the lake. Assuming that resolution of silicon from diatom frustules is slow and not completely reversible (frustules are found in sediments) and the Churchill River is the only quantitatively important source of silicon then a turnover time of less than 100 days again seems justified for the Churchill River plume. The high turnover time for this plume necessitates that those areas of the lake off the plume have very much longer turnover times and poorer exchange with the Churchill River.


5
4
3
7
2
1
0
6
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

GEOGRAPHIC REGIONS SET UP BY THE FISHERIES LIMNOLOGY COMPONENT

(note arrows indicate direction of flow of major streams)

Figure 2.3.1.1.

Table 2.2.1.1. Comparison of water flows before and after impoundment, based on Fisheries-Limnology estimates.

		Est. annual mean flow before impoundment	Est. annual mean flow after impoundment
Drainage into SIL at Opachaunau	cfs	31,800	31,800
Regions 1 and 7	cfs	960	960
South Bay	cfs	170	170
Diversion Channel	cfs	0	30,000
West shore of SIL	cfs	350	350
East shore of SIL	cfs	260	260
Region 5	cfs	1,100	1,100
Islands	cfs	92	92
Rainfall	cfs	160	200
Missi	cfs	34,900	5,000
Missi (Water Resources)		35,500	5,800

Table 2.2.1.2. Comparison of stream flows into Southern Indian Lake.

Muskwesi	613.	cfs	22	
Waddi	269.	cfs	9	
McLeod Lake stream	161.	cfs	6	
Station 79 (see Fig. 2.3.1.2.)	496.	cfs	17	
Sub total	1,540.	cfs	54	
Other streams, see Appendix I	1,292.	cfs	46	
Total flow in SIL from all streams other than Churchill River	2,831.00	cfs	100	%

Table 2.2.1.3. Comparison of stream discharge, by areas, Southern Indian Lake.

Area including islands	Drainage area in miles^2	cfs
South Bay (101-106A)	247	170
Above Sand Point (58-80)	1,630.	1,100
East side (81-100, excl. 83)	382.	260
West side (41-57)	519.	350
Regions 1&7 (106-109 & 8-40)	1,416.	960
Islands	136.	92

Table 2.2.1.4. Comparison of sodium and silicon concentration, Southern Indian Lake, 1972.

Sodium

Stations	10	20	30	40
June 21	2.1	2.3	2.6	2.7
July 10	2.1	2.2	2.3	2.5
August 1	2.2	2.1	2.2	2.4
August 21	2.6	2.3	2.2	2.4
September 12	2.7	2.5	2.2	2.3
October 3	2.8	2.6	2.5	2.4
December 10	3.3	3.3	-	3.0

underlined: minimum sodium concentration at each station. Note timing for each station.

Silicon

	09	10	20	30	40	49B
June 1	1.3					0.7
June 21	0.8	0.7	0.6	0.4	0.4	0.5
July 10	1.0	0.9	0.8	0.7	0.5	0.3
August 1	0.7	0.9	0.9	0.8	0.3	0.4
August 21	0.8	0.9	0.9	1.0	0.7	0.5
September 12	1.3	1.0	0.8	0.7	0.5	0.5
October 3	1.3	1.2	1.0	0.6	-	0.3
December 10	-	1.7	1.8	-	1.3	
March 28	1.6	1.5	1.6	-	1.5	1.5

underlined: stations considered to be affected by Si recharge from Churchill River subsequent to spring diatom bloom. Note timing for each station.

2.3.1. METHODS OF CHEMICAL ANALYSIS

Southern Indian Lake is a large lake with a complex shoreline. Because of the complexity of the basin, it was felt that one or two stations would be inadequate to characterize the chemical limnology of the entire lake. Also the proposed development will differ greatly in impact for different areas of the lake because of the diversion aspect. For these reasons Southern Indian Lake was divided into seven regions (see Figure 2.2.1.1), bounded by significant channel constrictions. Main chemistry stations were located at the deepest locations in each region, at major streams and at the outflow (see Figure 2.3.1.2 for locations). The stations were monitored seven times between June and October and three times between December and March.

Sampling was conducted from a fixed-wing aircraft and water was collected with a van Dorn sampler. Water samples (500 cc) were packed with ice and shipped in dark coolers to the Freshwater Institute, Department of the Environment. Samples were usually analyzed within 24 hours of collection. Temperature, dissolved oxygen, specific conductance and transparency determinations were done in the field. Temperature (°C) and dissolved oxygen (ppm) were measured with a YSI model 54 meter. The dissolved oxygen meter was calibrated by Winkler analyses. Specific conductance was measured with a YSI SCT meter, and transparency was estimated using a 20 cm Secchi disc having alternate black and white quadrants. Chlorophyll was also sampled in the field by filtering 200 cc of water through an ignited GF-C Whatman glass fiber filter. A 250 ml water sample treated with Lugol's solution was also collected for analysis of phytoplankton composition and abundance (Hecky, 1974).

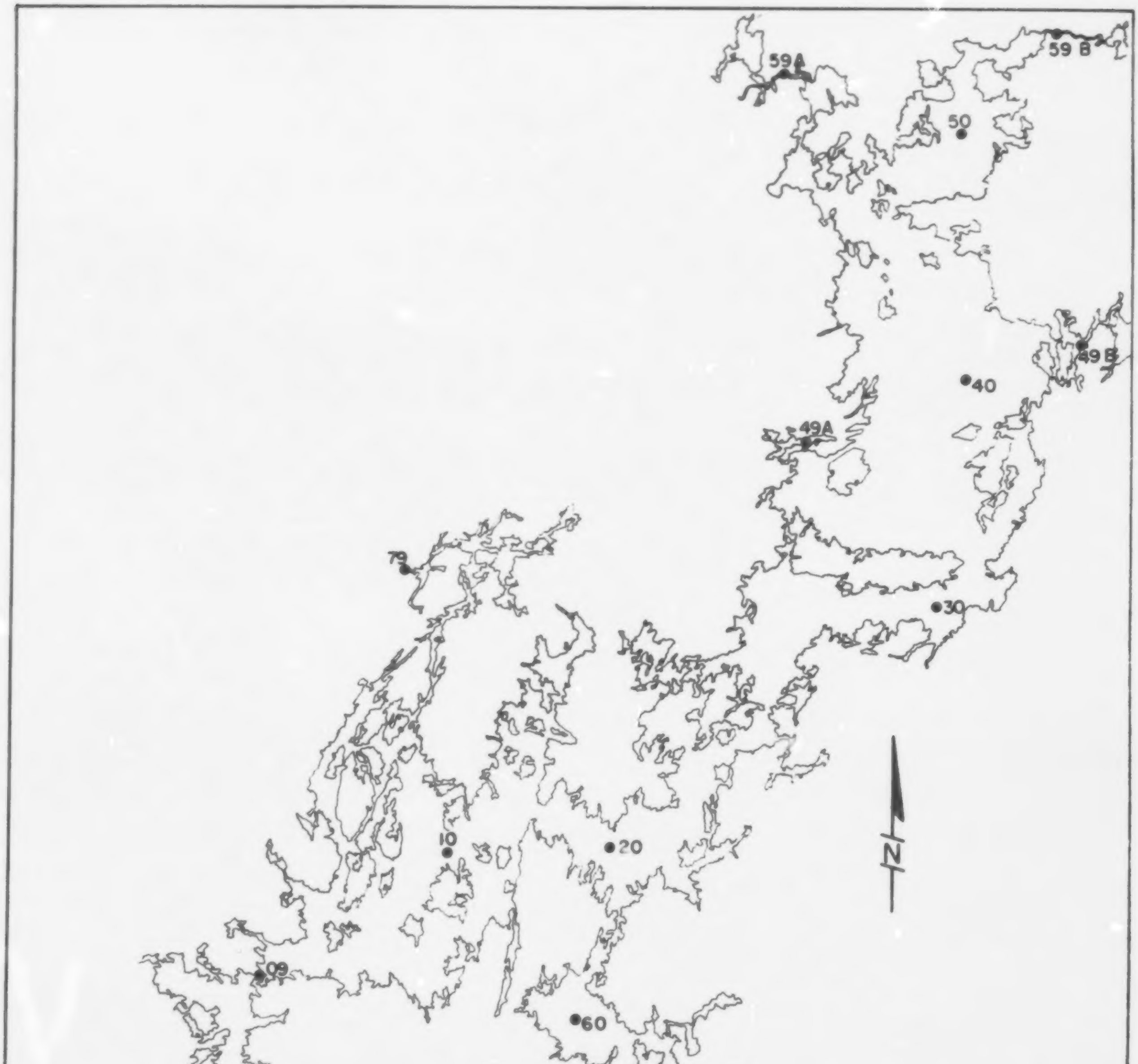
Additional synoptic chemistry stations were done by boat in early July, 1972 and late August, 1972. In contrast to the main chemistry sampling, there were several synoptic chemistry stations (Appendix IV) within every region. These samples complemented the main chemistry sampling by demonstrating the horizontal distribution within each region. At each station a temperature depth profile and Secchi measurements were taken. Water samples were taken at 0.5 meters and kept cool during transport to the Freshwater Institute for analysis. The samples were analyzed within 2 weeks of the sampling date. These samples are discussed in this report as well as in Patalas (1974) and Hamilton (1974).

The majority of streams flowing into Southern Indian Lake were also sampled for water chemistry on the 27th of August 1972 by helicopter. The streams were sampled at 0.5 meter depth. The samples were ice-packed and shipped in dark coolers for analysis within 24 hours of sampling. Colour (U.S. Geological Survey units) was done on these samples.

Procedure for sample preparation of synoptic stations and the main stations with the chemical species analyzed are given in Tables 2.3.1.1 and 2.3.1.2. Chemical species analyzed at the main stations are listed in Appendix II, Table I. All analytical determinations and calculations are described in Standard Methods (American Public Health Association, 1971) and Armstrong and Schindler (1971).

Ionic balances were calculated for the entire sampling, however, total inorganic carbon analysis procedures were unreliable until early

August. Thus the balances are indicative of the analysis only after the methodology for total CO_2 improved. Between August and November, in over 80% of the analyses, the balances between the ions are within 75-88%, showing a fairly reliable and consistent analytical procedure.


59A
59 B
50
49B
40
49A
79
30
10
20
09
60
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

MAIN CHEMISTRY STATIONS

Figure 2.3.1.2

Table 2.3.1.1. Procedure for sample preparation, synoptic chemistry stations, prior to analysis.

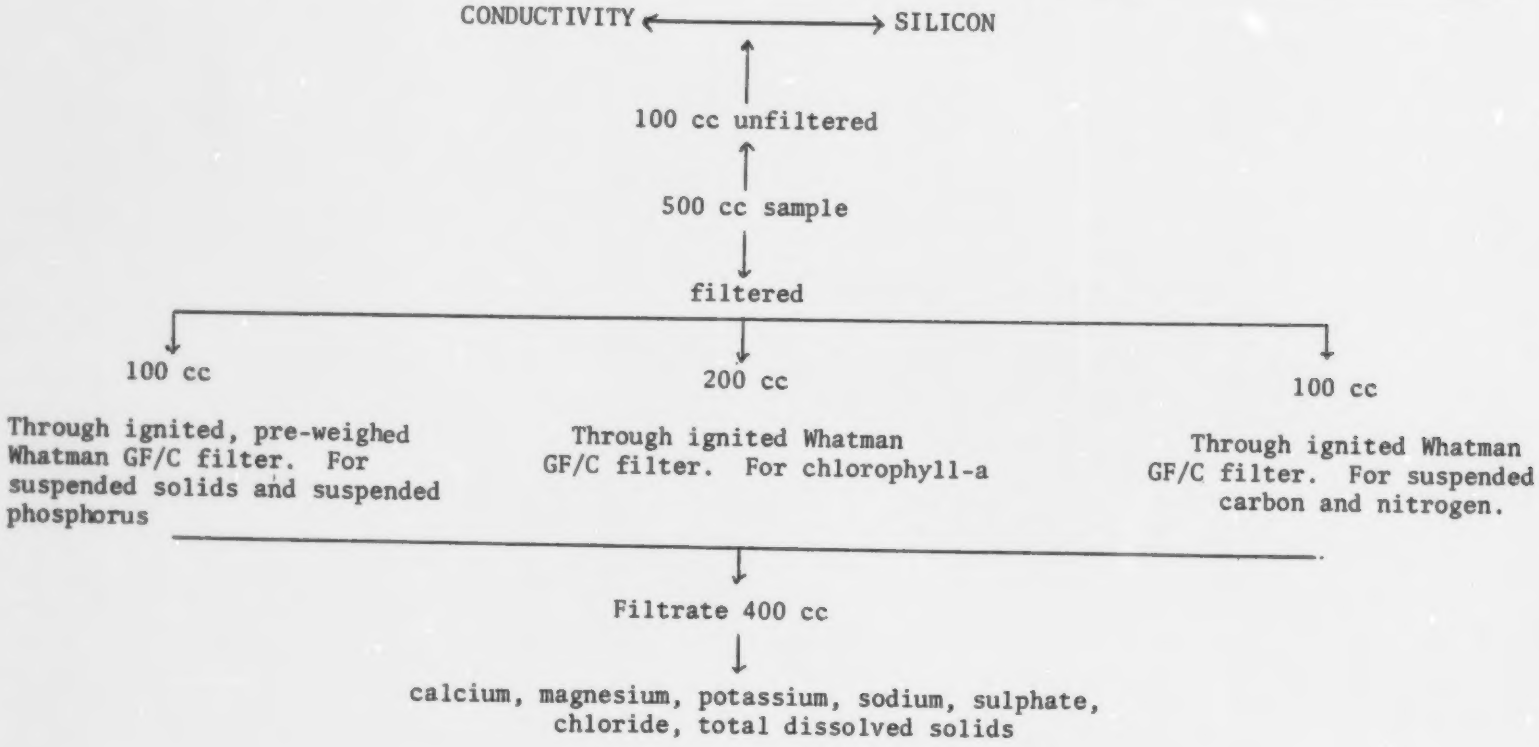
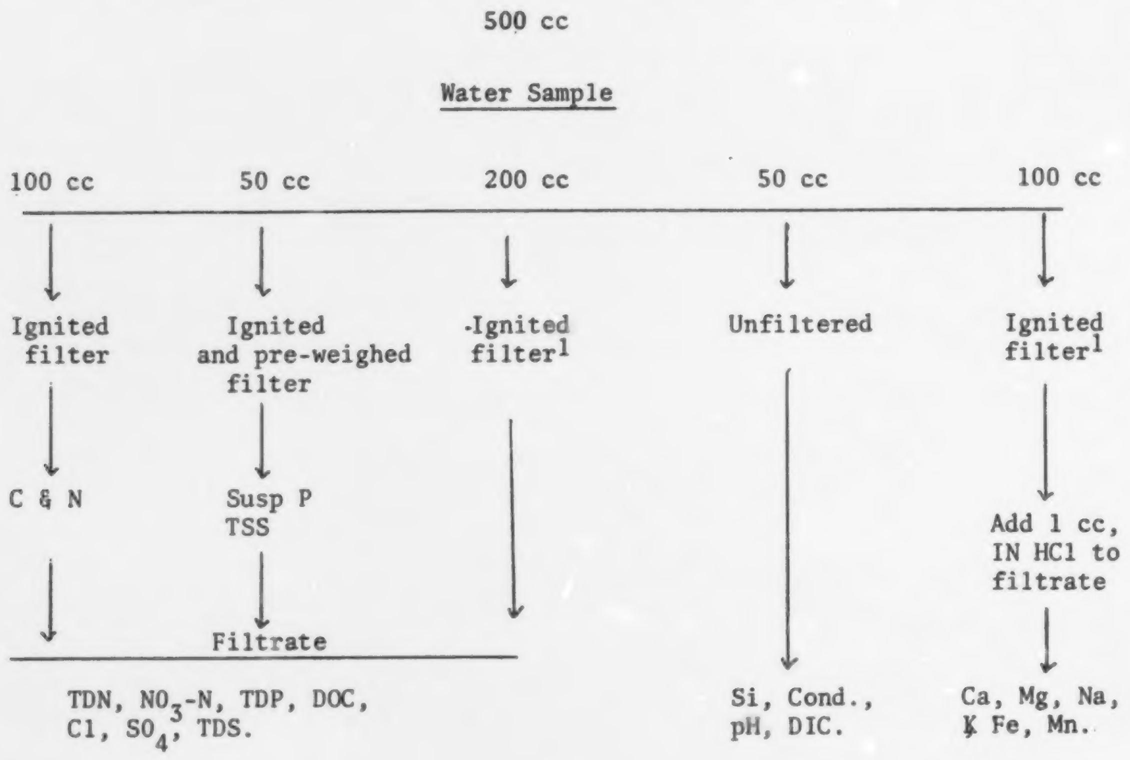

CONDUCTIVITY
SILICON
100 cc unfiltered
500 cc sample
filtered
100 cc
Through ignited, pre-weighed Whatman GF/C filter. For suspended solids and suspended phosphorus
200 cc
Through ignited Whatman GF/C filter. For chlorophyll-a
100 cc
Through ignited Whatman GF/C filter. For suspended carbon and nitrogen.
Filtrate 400 cc
calcium, magnesium, potassium, sodium, sulphate, chloride, total dissolved solids

Table 2.3.1.2. Procedure for sample analysis, main stations. TSS = total suspended solids, TDN = total dissolved nitrogen, TDP - total dissolved phosphorus, DOC = dissolved organic carbon, DIC = dissolved inorganic carbon.


500 cc
Water Sample
100 cc
50 cc
200 cc
50 cc
100 cc
Ignited filter
Ignited and pre-weighed filter
Ignited filter1
Unfiltered
Ignited filter1
C & N
Susp P
TSS
Add 1 cc, IN HCl to filtrate
Filtrate
TDN, NO3-N, TDP, DOC, Cl, SO4, TDS.
Si, Cond., pH, DIC.
Ca, Mg, Na, K Fe, Mn.

---

1. Filter paper discarded.
2. All filter papers are Whatman GF/C.
3. Chlorophyll was filtered in the field and the filtrate discarded.

2.3.2. FIELD OBSERVATIONS

Transparency.

Southern Indian Lake is untransparent relative to Shield lakes. Secchi disc depths range from 1-2.5 meters. The high light extinction is due to high turbidity from suspended clays. Compared to eleven Churchill River and Shield lakes in Table 2.3.4.5, Southern Indian Lake has the lowest observed mean Secchi depths and is lower than the average (2.5 m) of other Churchill River lakes.

Two trends appear in Secchi transparency (Table 2.3.2.1). The first is that all stations have a peak transparency in early August. The second is a greater Secchi depth progressing from station 10 to 40. This increasing Secchi depth with distance from station 09 (inflow) probably results from sedimentation of fine suspended material during residence in the lake.

Oxygen.

Observations on dissolved oxygen were made in conjunction with temperatures. Detailed oxygen observations are shown in Appendix V. Surface and 1/2 meter water was always 90% or greater saturation of dissolved oxygen. In late winter, station 60, at bottom plus one meter, had a 67% oxygen saturation, the lowest oxygen saturation observed. Other than this one observation, the bottom plus one meter depth was always above 75% oxygen saturation between May 1972 and March 1973.

Ice and snow.

Detailed ice and snow observations were made at every opportunity, and depths recorded (Tables 2.3.2.2 and 2.3.2.3) on each sampling trip. Stations 09 and 49B did not freeze up in the winter of 1972, probably because of the high current velocities and resulting turbulence of these rapids.

Ice first appeared at station 50 near the end of October with freeze-up about November 1. Station 10, the last to freeze up, was approximately two weeks later. Station 60 was similar to station 20 which was 2-5 days before station 10. Station 10 was the first to break up in late May, and station 50, the last to break up, was not ice-free until mid-June 1972. Freeze-up in most streams was about one week later than the lake, with breakup in mid-May.

Thermal regime.

Detailed temperature profiles from each visit are shown in Appendix V, and summarized in Table 2.3.2.4. A total of 14 temperature profiles were taken at each major station from May 1972 to March 1973. Seasonal isotherms for the main stations are presented in Appendix V, Figures 8 and 9. Vertical profiles for stations 20 and 60 are given in Appendix V, Figures 10 and 11.

The maximum summer vertical temperature gradient was 3.1°C at station 40 on July 11, 1973. Some winter stratification was observed at all six main stations during the winter. Stations 40 and 60 showed the maximum gradient observed (4°C), station 10 had the lowest gradient

(2°C). The Churchill River at 09 is typically near 0°C (0° to -0.5°C) through the winter and import of this water into region 1 should cool the lake noticeably. The cooling influence would not be as noticeable at station 40 as the plume would have been warmed by the passage through other regions (2 and 3).

Examination of the temperature profiles in Appendix V shows that at any time within Southern Indian Lake, station 60 has the warmest mean temperature followed by 10, 20, 30 and 40, with the coldest station being 50. The local streams (Table 2.3.3.2) have a warmer mean summer temperature than Southern Indian Lake. The maximum temperatures occurred in mid- to late-August, 1972. Station 50 warms and cools very quickly; 7.5°C on June 21, 1972 to 15.1°C on July 11, 1972, and 17.4°C on August 21, 1972 to 9.8°C on September 11, 1972. Station 40, as a consequence of the mass of water, takes the longest to warm up in spring and cool down in fall.

Observations in isolated areas (Appendix V, Tables 2 and 3) revealed some distinct stratification at some stations. This is related to their greater wind protection relative to the main basin of Southern Indian Lake.

The summer heat budget of a lake is the amount of heat (Θ_{bs}) required to raise the temperature from 4°C to its maximum heat content (Table 2.3.2.5). In most large lakes heat transfer through the lake's surface is the overwhelming source of heat income while heat contributed by inflows is minor (Hutchinson, 1957). The Churchill River mainstream lakes receive the top warm water from the

Table 2.3.2.1. Comparison of Secchi depth transparency (m) in Southern Indian Lake, 1972.

	Station					
	10	20	30	40	50	60
June 21	1.3	1.3	1.4	2.2	2.0	1.3
July 11	1.3	1.3	1.5	2.0	1.9	1.3
Aug. 1	1.3	1.5	1.7	1.6	1.8	1.4
Aug. 21	1.7	1.7	2.0	2.5	2.5	1.6
Sept 11	1.5	1.6	1.7	2.1	2.0	1.5
Oct. 3	1.0	1.2	1.4	1.8	1.6	1.1

Table 2.3.2.2. Comparison of ice thickness (in.), Southern Indian Lake, 1972.

	10	20	30	40	50	60
Dec. 10/72	11	16	-	12	19.5	14
Feb. 28/73	32	-	-	25	39	36
Mar. 28/73	42	42	-	42	39	36

Table 2.3.2.3. Comparison of snow thickness (in.), Southern Indian Lake, 1972.

	10	20	30	40	50	60
Dec. 10/72	11	12	-	14	16	12
Feb. 28/73	20	24	-	25	22	20
Mar. 28/73	16	17	-	20	21	17

Table 2.3.2.4. Maximum, minimum and mean observed temperatures (°C) at each major station, June-October, 1972, depth 0.5 meters.

Station	10	20	30	40	50	60	09	79	49A	59A	59B	49B
Minimum temp	5.75	6.0	5.75	6.25	5.3	6.0	6	10	9.8	8.5	8.8	5.5
Mean temp	12.9	12.7	12.4	11.5	10.7	13.0	13.6	15	14.3	13.5	13.8	11.0
Maximum temp	17.6	17.6	17.5	16.1	17.4	16.8	17.5	18.9	18.8	18	18.2	15.1

lakes immediately upstream in the drainage basin, and in riverine lakes, with a rapid exchange rate, spring warming may be accelerated in comparison to other Shield lakes (Koshinsky, 1971). Therefore, the total heat input of the Churchill River into Southern Indian Lake was estimated in order to see if the river-contributed heat is a major portion of the total heat income of the lake. The heating period was divided into two parts, 31 May to 21 June and 21 June to 11 July, 1972, during which the lake exhibited maximum heat gain. The amount of heat contributed by the Churchill River to Southern Indian Lake for a given time interval is calculated by the following formula:

$$H_R = DT\ (t_R - t_L)\ C_p$$

where C_p = specific heat of water

H_R = heat input from the river (calories)

D = mean discharge for time period (cm^3/sec)

T = time interval (in seconds)

t_R = mean temperature of river during interval

t_L = mean temperature of lake during time interval

The values for these parameters of the two time periods are given in Table 2.3.2.6.

The formula for total heat gain of a lake or a lake region for a given time period is calculated by the formula:

$$H_T = Vw\ (t_2 - t_1)\ C_p + V_I P_I \theta_f$$

where H_T = total heat gain for time interval (calories)

V_w = volume of water (grams)

V_I = volume of ice (grams)

ρ_I = density of ice

θ_f = latent heat of fusion of water (80 cal/gm)

t_2 = temperature of homogeneous water mass at end of time period, °C

t_1 = initial temperature (assumed 4°C immediately after ice-out).

The values for these parameters of the two time periods are given in Table 2.3.2.7.

The heat required as calculated in Table 2.3.2.8 shows that the Churchill River supplies only 1.3% of the total heat added to the lake. If only region 1 is considered as receiving heat from the Churchill River then the river supplies approximately 2.7% of the total heat gained. Prior to ice-out in region 1, the river may have supplied an even larger proportion of heat income as the river was ice-free and temperature equilibrated with the atmosphere. But consideration of the late spring heat budget given in Table 2.3.2.8 demonstrates that the river can have little effect on heating of regions 3 and 4. Therefore, diversion through South Bay should have little effect on the timing of ice-out and the total heat budget for regions 3, 4 and 5.

Table 2.3.2.5. Summer heat budgets (from 4°C to summer maximum), for Southern Indian Lake, by regions.

Region	Area	Volume	$\bar{z}$ meters	Θ_{bs}	
1	$646.67\text{x}10^{6}m^{2}$	$4.01\text{x}10^{9}m^{3}$	8.45	$6.82 \text{ x } 10^{3}$	cal/cm^{2}
2	$285.8\ \text{x}10^{6}m^{2}$	$1.8\ \text{x}10^{9}m^{3}$	8.08	$3.04 \text{ x } 10^{3}$	cal/cm^{2}
3	$215.18\text{x}10^{6}m^{2}$	$1.85\text{x}10^{9}m^{3}$	9.25	$2.77 \text{ x } 10^{3}$	cal/cm^{2}
4	$715.13\text{x}10^{6}m^{2}$	$7.93\text{x}10^{9}m^{3}$	12.65	$12.1 \text{ x } 10^{3}$	cal/cm^{2}
5	$218.93\text{x}10^{6}m^{2}$	$1.12\text{x}10^{9}m^{3}$	5.32	$1.42 \text{ x } 10^{3}$	cal/cm^{2}
6	$124.53\text{x}10^{6}m^{2}$	$0.47\text{x}10^{9}m^{3}$	3.90	$1.01 \text{ x } 10^{3}$	cal/cm^{2}

Table 2.3.2.6. Heat contribution of the Churchill River for two time periods during 1972.

	31 May - 21 June	21 June - 11 July
Cp	1 cal	1 cal
D	1.02×10^9 cm^3	1.02×10^9 cm^3
T	1814400 seconds (21 days)	1728000 seconds (20 days)
$t_R - t_L$	2.55°C	1.85°C
H_R	4.72×10^{15} cal/sec	3.26×10^{15} cal/sec

Table 2.3.2.7. Heat gain of each region in Southern Indian Lake for two time periods during 1972.

Region No.	1		2		3	
Time	31/5 to 21/6	21/6 to 11/7	31/5 to 21/6	21/6 to 11/7	31/5 to 21/6	21/6 to 11/7
θ_f	80 cal/gm	-	80 cal/gm	-	80 cal/gm	-
ρ_I	0.9	-	0.9	-	0.9	-
V_I	232.4×10^{12} gm	-	142.9×10^{12} gm	-	107.59×10^{12} gm	-
C_p	1 cal	1 cal	1 cal	1 cal	1 cal	1 cal
$t_2 - t_1$	6.7°C	4.5°C	5.8°C	5.4°C	5.0°C	5.8°C
V_w	4.01×10^{15} gm	4.01×10^{15} gm	1.8×10^{15} gm	1.8×10^{15} gm	1.85×10^{15} gm	1.85×10^{15} gm
H_T	5.02×10^{16}	1.8×10^{16}	2.07×10^{16}	0.97×10^{16}	1.7×10^{16}	1.07×10^{16}

Region	4		5		6	
Time	31/5 to 21/6	21/6 to 11/7	31/5 to 21/6	21/6 to 11/7	31/5 to 21/6	21/6 to 11/7
θ_f	80 cal/gm	-	80 cal/gm	-	80 cal/gm	-
ρ_I	0.9	-	0.9	-	0.9	-
V_I	357.5×10^{12} gm	-	109.5×10^{12} gm	-	62.27×10^{12} gm	-
C_p	1 cal	1 cal	1 cal	1 cal	1 cal	1 cal
$t_2 - t_1$	4.9°C	7.1°C	4.9°C	7.2°C	7.9°C	4.2°C
V_w	7.93×10^{15} gm	7.93×10^{15}	1.12×10^{15} gm	1.12×10^{15} gm	0.47×10^{15} gm	0.47×10^{15} gm
H_T	6.5×10^{16}	5.6×10^{16}	1.34×10^{16}	0.8×10^{16}	0.82×10^{16}	0.19×10^{16}

Table 2.3.2.8. Comparison of H_R and H_T for Southern Indian Lake and region 1, and a percentage attributable to the Churchill River inflow.

H_R river input - 4°C to maximum	H_T heat gain - 4°C to maximum			
	Region one	$\% \frac{H_R}{H_T}$	Whole Lake	$\% \frac{H_R}{H_T}$
7.98×10^{15} cal/sec or 8.64 cal/cm^2/day	3.24×10^2 cal/cm^2/day	2.7	6.62×10^2 cal/cm^2/day	1.3

2.3.3. STREAMS, CHEMICAL SURVEY

An extensive stream survey was conducted in August 1972 in order to evaluate the water quality of streams. Samples were collected near the outflow of each stream (see Figure 2.3.3.1 for location). The results of chemical analyses are presented in Appendix VI.

The water quality of a stream depends to a large degree upon the soil in the watershed. Microbiological activity, ion exchange and leaching of organic and mineral material all alter the water quality. The variable soil types (Can. Dept. of Energy, Mines & Resources, 1968) around Southern Indian Lake produce streams of varying water quality. The streams of various regions are characterized by their chemical parameters in Table 2.3.3.1. In general, the streams flowing into regions 1 and 7 are chemically similar, and they tend to be intermediate in concentrations of Na, Mg, Ca, and TDS between streams entering from the western shore and north of Sand Point and streams entering from the eastern shore and into South Bay. The streams from the eastern shore and South Bay have much higher concentrations of Na, Mg, Ca, and TDS while streams from the west and north of Sand Point have much lower concentrations of these constituents. The difference in concentration probably reflects the areal coverage by glacio-lacustrine clays in the drainage systems. Clay coverage is thicker and more extensive to the south of Southern Indian Lake and thins markedly to the north. These small streams can be compared with Opachuanau Rapids and Missi Rapids in Table 2.3.3.1. The

Churchill River has much higher Na and K concentrations and lower concentrations of Ca, Mg, TDS, color, and TDN. The local drainage into Southern Indian Lake has little affect on the chemical composition as can be seen by comparing Opachuanau Rapids (09) and Missi Rapids (49B) with each other and the local streams. The Churchill River presently determines the chemical composition of Southern Indian Lake, and local streams are a minor entry in the chemical budget.

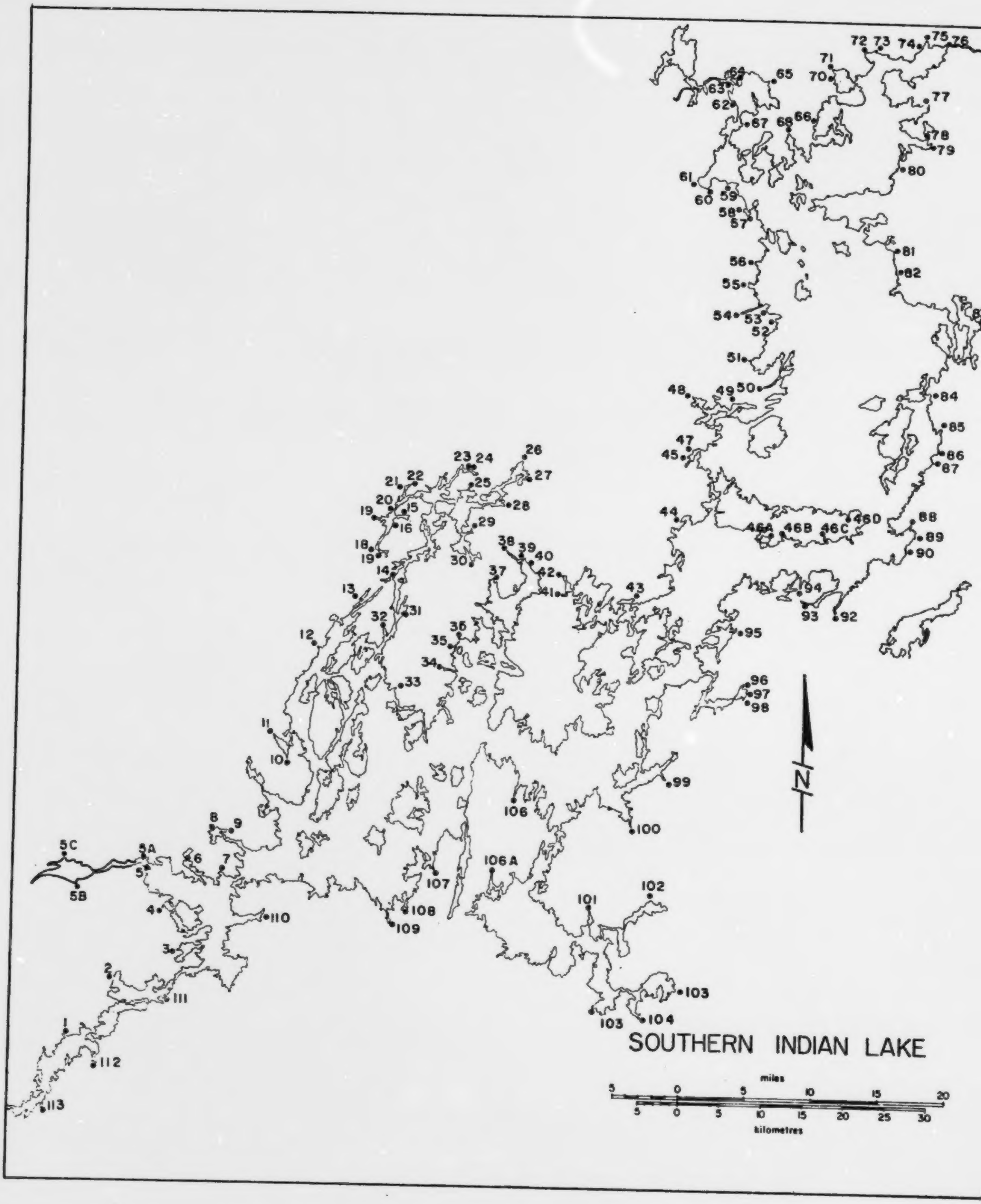

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Figure 2.3.3.1. Locations of streams sampled on August 27, 1972.

Table 2.3.3.1. Average concentrations of chemical parameters for streams in each area in August.

Area	09	1 + 7[1] intermediate	South Bay	South and East SIL	North and West SIL[3]	Above S.Pt[2]	49B
Streams	-	106-109,8-40	101-106A	81-100	41-57	58-80	-
Si	0.84	1.36	1.92	1.8	0.4	1.14	0.61
Na	2.76	2.03	2.29	2.0	1.47	1.44	2.26
K	1.17	0.77	0.68	0.55	0.62	0.45	0.98
Mg	4.16	6.37	7.5	7.2	4.42	4.85	3.43
Ca	9.5	19.5	25.4	25.5	13.5	15.6	8.3
Colour	10	50	50	50	50	60	10
Cond	85	138	169	165	95	106	75
TDS	74	85	142	128	71	82	55
NO_3	5	11	5	8	6	6	6
TDN	299	434	377	374	417	365	226
Susp N	75	97	49	35	94	83	132
TDP	3	10	7	13	13	16	10
Susp P	8	10	8	7	12	9	8

1. includes stream 79
2. includes streams 59A and 59B, above Sand Point.
3. includes stream 49A

2.3.4. CHEMICAL ANALYSIS, MAIN STATIONS

The complete results of chemical analysis of water from the main stations are recorded in Appendix II. Mean values of selected chemical species are summarized in Table 2.3.4.4. A summary of annual range, summer mean and annual mean (mean of all analyses), for all chemical parameters at each station, are recorded in Table 2.3.4.3. A comparison with other Churchill River and Shield lakes is presented in Table 2.3.4.5. Figures 1 to 42 in Appendix II graphically present each chemical paramater on a station-to-time-to-concentration basis. Figures 43 and 44 (Appendix II) show the lack of chemical stratification for two stations and t parameters. Appendix II, Figure 45 compares some water components at major chemical stations. This figure demonstrates the chemical similarity of stations 09, 10, 20, 30, 40 and 49B and the dissimilarity of stations 50 and 60 which are isolated from the Churchill River. Locations of the major stations are indicated on Figure 2.3.1.2. Station 50, although chemically different from the Churchill River stations, cannot be derived simply from the two major tributaries to region 5 (see Table 2.3.4.2). There must be some long-term interchange with region 4 water to account for the higher Na and K. Simple mixture assumptions would suggest that 25% of the water in region 5 is from region 4.

Cations

The 1972-73 yearly mean concentrations of sodium and potassium in the Churchill River at station (09) were 2.9 mg/1 and 1.2 mg/1 respectively.

Stations 10, 20, 30, 40 and the outlet all had yearly mean concentrations of approximately 2.4 to 2.5 mg/l of sodium and 1.1 to 1.2 mg/l of potassium. Stations 50 and 60 had lower values of both ions. South Bay had a yearly mean of 2.1 mg/l of sodium and 0.9 mg/l of potassium. Station 50 had the lowest concentrations of both ions, 1.8 mg/l of sodium and 0.7 mg/l of potassium.

Magnesium and calcium had a yearly mean of 3.9 mg/l and 9 mg/l respectively at the inlet (09). The Churchill River plume stations (10, 20, 30, 40) and the outlet all had mean concentrations of approximately 3.5-3.7 mg/l of magnesium and 8.5 to 9.4 mg/l of calcium. Station 50 had a yearly mean of 3.6 mg/l of magnesium and 11.8 mg/l of calcium. Station 60 had a relatively high concentration of both ions at 5.3 mg/l of magnesium and 21.4 mg/l of calcium. The higher values at 60 probably reflect the streams leaching the high proportion of glacial till in the area.

Anions

Chloride and sulphate concentrations were low and relatively uniform in distribution throughout the lake, both horizontally and vertically during 1972-73. No trends could be observed. Chloride concentrations of 1 mg/l and sulphate concentrations of 4 mg/l remained constant in summer and winter analysis at all sampling stations.

Silicon decreased in concentration from station 09 through the main basin to station 49B (lowest concentration). Silicon is retained within the lake ecosystem during the summer months. Concentrations of silicon increase within the lake during winter, when ice and snow cover limit light and diatom production. See section 2.2.1 for further description of silicon concentrations within the lake.

Total CO_2 analyses for the 1972-73 field sampling are recorded in Appendix III. The computed breakdown and the program used are also recorded in Appendix III. Total CO_2 analyses, 1 June, 1972 to 1 August, 1972 is probably unreliable due to analytical procedures, and they are not used in the data analysis.

Due to the unreliable data no trend could be discerned for the majority of the lake. South Bay, station 60, however, did consistently show twice the concentration of inorganic carbon of all other main statio on Southern Indian Lake.

Chlorophyll a

Average concentrations of chlorophyll in Southern Indian Lake, are relatively low, see Table 2.3.4.3. South Bay had the lowest average concentration observed with a summer mean of 2.4 μg/l. The mean summer chlorophyll concentrations for the remainder of the lake ranged from 2.6-4.8. The peak concentration, 12.9 μg/l, observed occurred in early September at station 20. Station 09, the inlet, and the outlet, 49B, had summer means of 4.6 μg/l and 4.5 μg/l respectively and yearly means of 3.6 μg/l. Stations 10 and 20 had the highest mean chlorophyll concentrat at 4.7-4.8 μg/l in the summer and yearly means of 4.1-4.3 μg/l. Station 30 had a lower summer mean, than stations 10 and 20, at 4.2 μg/l and station 40, a highly productive commercial fishing area, (Weagle and

Baxter, 1973), had the second lowest chlorophyll concentration with a summer mean of 2.6 μg/l and a yearly mean of 2.2 μg/l. Both stations 50 and 60 had low chlorophyll concentrations with summer mean values of 2.6-2.4 μg/l and yearly means of 2.1 μg/l.

Phosphorus

All sources into Southern Indian Lake, the Churchill River and all other local streams appear, see Table 2.3.4.3, to have similar concentratio of total phosphorus (TDP + suspended P). The Churchill River is overwhelmingly important to phosphorus loading only because of the volume of discharge, not because of a higher concentration of phosphorus. The Churchill River and the streams had a summer mean of 12.4 μg/l in 1972 of TDP. The Churchill River plume stations (10, 20, 30, 40) had a summer mean of 9 μg/l of TDP. Suspended phosphorus was similar at all main stations at 9-10 μg/l (summer mean) while the Churchill River input was 12.4 μg/l.

Nitrogen

Nitrate-nitrogen values in summer seldom exceeded 10 μg/l at stations 10, 20, 30, 40, 50 and 60, but increases during winter to 80 μg/l at stations 10, 20, 30 and 40, the Churchill River plume stations. Stations 50 and 60, had much lower winter NO_3-N concentrations at 21-26 μg/l. The inlet and outlet had summer mean NO_3-N concentrations of 21-24 μg/l and winter concentrations up to 85 μg/l. The distribution of nitrate-nitrogen in time and space clearly indicates the significance of the river to the nitrogen cycle through winter recharge.

Total dissolved nitrogen at the inlet and outlet had yearly
of 330 and 337 μg/l respectively. Stations 10, 20, 30, and 40 had
mean concentrations between 280-300 μg/l and stations 50 and 60 wer
a little lower at 250-260 μg/l of TDN. Suspended nitrogen had simi
concentrations at all stations between summer and winter values. T
out the year 09 had the highest concentration of suspended N with a
value of 112 μg/l, station 10 (85 μg/l), 20 (78 μg/l), 30 (76 μg/l)
40 (65 μg/l) were progressively less concentrated than the Churchil
inlet water. This pattern probably reflects sedimentation of alloc
suspended N. Station 50 had a yearly mean concentration of 51 μg/l
station 60 had the lowest concentration at 39 μg/l.

pH

Hydrogen ion activity was relatively similar between statio
the main lake basin as all stations had yearly means around 7.8 wi
range from 7.5 to 8. In South Bay, station 60, pH values were cons
higher with a mean pH value of 8.1, range from 8.0 to 8.2. Statio
values were the same as the main basin, at approximately 7.8.

Specific conductance and total dissolved solids

The highest recorded values for TDS and conductance were rec
at South Bay, station 60. Specific conductance ranged from 131-16
in South Bay which compares with a range of 68-95 μmho/cm for all c
stations in the lake. TDS ranged from 44 to 122 mg/l with a yearl

of less than 69 mg/l, station 10 had the lowest mean at 57 mg/l and station 40 had the highest mean (other than 60) at 68 mg/l.

Spatio-temporal relationships

With few exceptions Southern Indian Lake appeared, in 1972-73, to have a similar chemical seasonality through all the main stations, Appendix II. The greatest variations were noted in nutrients which appeared to react at approximately the same times. Generally all the stations had peak and low concentrations at approximately the same time. Nitrate, for example, at all main stations (except 09) appeared to have a peak summer concentration on approximately July 10, 1972. As this peak followed the annual minimum it may represent regeneration from the spring diatom bloom. The concentration of NO_3-N leveled off at a lower value through the remainder of the summer and increased to a higher value during winter, see Table 2.3.4.6. The high winter nitrate concentrations are typical of lakes where winter conditions favor nitrification for bacteria, over nitrate reduction and assimilation by microorganisms (Hutchinson, 1951). The inlet, station 09, showed a similar nitrate spatio-temporal distribution, except the high concentration in the spring lasted from the first sampling (June 1) until August 10, 1972. This probably reflects less efficient utilization in the turbid river by phytoplankton. Decline after August 10 may indicate that nutrient depleted waters from upstream Churchill River lakes begins to enter Southern Indian Lake.

Suspended phosphorus and suspended nitrogen, at all main stations, were at their greatest concentrations during mid-summer, August 1 to

September 12, at approximately the same time TDP and TDN appeared their lowest concentrations within Southern Indian Lake. Chlorop reached highest concentrations at stations 10, 20 and 30, on 12 S 1972, while stations 09, 40 and 50 peaked approximately three wee earlier. Station 60, South Bay, and 49B, the outlet, had a peak concentration on 4 October 1972. All other chemical species appe be relatively stable through the sampling period, with the except sodium and silicon. The spatial-temporal distribution of these e within the lake during 1972-73, was discussed in section 2.2.1.

Table 2.3.4.2. Comparison of summer means of the three major stations in Region 5, Southern Indian Lake.

	Station 50	Station 59A	Station 5
Si mg/l	0.492	0.652	0.821
Na mg/l	1.635	1.073	0.891
K mg/l	0.678	0.352	0.425
Mg mg/l	3.442	3.148	3.4
Ca mg/l	11.695	11.758	12.088
NO_3 μg/l	8.83	13.80	15.6
TDN μg/l	263.16	427.5	322
Susp N μg/l	61.8	103.33	98.3
TDP μg/l	10.16	14.167	10.5
Susp P μg/l	6.8	13.167	9.0
Chl a μg/l	2.6	3.8	2.7
Cond. μmho/cm	82	75	81.8
pH	7.84	7.9	7.87
TDS μg/l	62	53.3	65

Table 2.3.4.3. Summary of chemical parameters, Southern Indian Lake,

	STATION 09		
	RANGE	SUMMER $\bar{x}$	YEARLY $\bar{x}$[1]
Total CO_2 (μmoles/l)	313-990	583	635
Cl^- (mg/l)	1.0 - 4.2	1.46	1.41
$SO_4^=$ (mg/l)	3.0 - 5.0	4.371	4.378
Si (mg/l)	0.71 - 1.55	1.024	1.124
Total anions (meq/l)	0.498- 1.208	0.8432	0.916
Na^+ (mg/l)	2.55 - 3.54	2.894	2.916
K^+ (mg/l)	1.02 - 1.58	1.191	1.218
Mg^+ (mg/l)	2.98 - 4.94	3.890	3.860
Ca (mg/l)	6.78 -10.6	8.89	8.98
Total cations (meq/l)	0.732- 1.119	0.920	0.923
Mn	0.01 - 0.03	0.014	0.016
Total Fe	0.03 - 0.19	0.104	0.09
NO_3-N	5. -85.	13.14	24.22
TDN	300. -450.	322.85	337.0
Susp N	36. -260	117.14	107.0
TDP	8. - 25	12.42	14.56
Susp P	4. - 20	13.00	11.111
Chl a	0.5 - 11.1	4.60	3.612
Cond	67. - 90.	76.42	77.667
pH	7.5 - 8.0	7.86	7.81
TDS	30. -107.	51.43	60.56
TSS	<10 - 10	<10	<10
Susp C	350 -920	737.14	673.11

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1. Yearly means are calculated by averaging each analysis, not averaging the summer and winter means.

STATION 49A

	RANGE	SUMMER $\bar{x}$
Total CO_2 (µmoles/l)	228-890	542.
Cl^- (mg/l)	1.0 - 1.0	1.0
$SO_4^=$ (mg/l)	2.0 - 4.0	3.48
Si (mg/l)	0.22 - 0.74	0.392
Total anions (meq/l)	0.404- 1.039	0.684
Na^+ (mg/l)	0.86 - 1.30	1.173
K^+ (mg/l)	0.37 - 0.66	0.553
Mg^+ (mg/l)	2.84 - 3.78	3.39
Ca^+ (mg/l)	9.05 -12.20	10.891
Total cations (meq/l)	0.791- 0.970	0.888
Mn (mg/l)	0.01 - 0.04	0.02
Total Fe (mg/l)	0.03 - 0.25	0.115
NO_3-N (µg/l)	5.0 -11.0	7.5
TDN (µg/l)	320. -450.	384.0
Susp P(µg/l)	100. -240.	156.67
TDP (µg/l)	6. - 14.	10.167
Susp P(µg/l)	15. - 22.	17.83
Chl a (µg/l)	2.1- 8.2	5.233
Cond (µmho/cm)	54 - 88	76.333
pH	7.7- 8.1	7.93
TDS (µg/l)	30. -100	60.
TSS (µg/l)	<10	<10
Susp C(µg/l)	890. -1460.	1131.667

STATION 59A (Muskwesi)

		RANGE	SUMMER $\bar{x}$
Total CO_2	(µmoles/l)	185. - 1000.	456.83-
Cl^-	(mg/l)	< 1.0- 1.5	1.12
$SO_4^=$	(mg/l)	2.4- 4.0	3.567
Si	(mg/l)	0.39 - 0.84	0.652
Total anions	(meq/l)	0.320- 0.733	0.518
Na^+	(mg/l)	0.98 - 1.18	1.073
K^+	(mg/l)	0.30 - 0.40	0.352
Mg^+	(mg/l)	2.26 - 3.98	3.148
Ca^+	(mg/l)	7.2 - 18.90	11.758
Total cations	(meq/l)	0.606- 0.980	0.7928
Mn	(mg/l)	0.02 - 0.07	0.043
Total Fe	(mg/l)	0.08 - 0.22	0.167
NO_3-N	(µg/l)	< 1 - 23	13.80
TDN	(µg/l)	350. - 550.	427.50
Susp N	(µg/l)	60. - 210	103.33
TDP	(µg/l)	8. - 22.	14.167
Susp P	(µg/l)	8. - 22.	13.167
Chl a	(µg/l)	2.0 - 5.6	3.80
Cond		65 - 91	75.0
pH		7.7 - 8.3	7.90
TDS	(µg/l)	30. - 90.	53.33
TSS	(µg/l)	<10	<10
Susp C	(µg/l)	420. - 920.	725.0

STATION 59B (Waddie)

		RANGE	SUMMER $\bar{x}$	YEARLY $\bar{x}$
Total CO_2	(µmoles/l)	169. - 1040.	595.333	573.143
Cl^-	(mg/l)	< 1. - 1.2	1.040	1.0333
$SO_4^=$	(mg/l)	3.0 - 4.1	3.517	3.586
Si	(mg/l)	0.49 - 1.64	0.821	0.939
Total anions	(meq/l)	0.450- 1.267	0.830	0.819
Na^+	(mg/l)	0.76 - 1.37	0.891	0.960
K^+	(mg/l)	0.32 - 0.80	0.425	0.450
Mg^+	(mg/l)	2.68 - 5.62	3.400	3.717
Ca^+	(mg/l)	7.30 - 21.00	12.088	13.370
Total cations	(meq/l)	0.661- 1.585	0.923	1.033
Mn	(mg/l)	0.01 - 0.05	0.030	0.025
Total Fe	(mg/l)	0.04 - 0.27	0.116	0.121
NO_3-N	(µg/l)	< 1. - 44.	15.600	17.000
TDN	(µg/l)	70. - 410.	322.000	340.000
Susp N	(µg/l)	60. - 220.	98.333	92.857
TDP	(µg/l)	6. - 20.	10.500	11.857
Susp P	(µg/l)	5. - 14.	9.000	8.429
Chl a	(µg/l)	0.4 - 4.8	2.717	2.429
Cond.		70. - 130.	81.833	88.721
pH		7.7 - 8.0	7.875	7.860
TDS	(µg/l)	50. - 120.	65.000	72.857
TSS	(µg/l)	<10	<10	<10
Susp C	(µg/l)	450. - 940.	668.333	707.143

STATION 49B

		RANGE	SUMMER $\bar{x}$	YEARLY $\bar{x}$
Total CO_2	(µmoles/l)	194. - 1080	547.710	614.250
Cl^-	(mg/l)	1.0 - 2.0	1.214	1.211
$SO_4^=$	(mg/l)	3.0 - 5.2	3.714	4.022
Si	(mg/l)	0.26 - 1.52	0.444	0.679
Total anions	(meq/l)	0.392- 1.049	0.700	0.812
Na^+	(mg/l)	2.21 - 3.25	2.300	2.503
K^+	(mg/l)	0.86 - 1.39	0.979	1.068
Mg^+	(mg/l)	2.82 - 4.64	3.474	3.711
Ca^+	(mg/l)	6.50 - 11.10	8.487	9.023
Total cations	(meq/l)	0.674- 1.073	0.715	0.864
Mn	(mg/l)	0.01 - 0.09	0.040	0.036
Total Fe	(mg/l)	0.01 - 0.19	0.055	0.0675
NO_3-N	(µg/l)	5. - 75.	11.571	21.889
TDN	(µg/l)	180. - 425.	304.285	330.444
Susp N	(µg/l)	32. - 210	93.857	83.667
TDP	(µg/l)	5. - 35.	10.286	15.000
Susp P	(µg/l)	3. - 12.	7.857	6.889
Chl a	(µg/l)	0.4 - 9.9	4.486	3.589
Cond		76. - 101.	81.429	85.111
pH		7.6 - 8.0	7.92	7.857
TDS	(µg/l)	40. - 125.	54.286	65.667
TSS	(µg/l)	<10	<10	<10
Susp C	(µg/l)	430. - 1030.	680.000	648.750

STATION 79

		RANGE	SUMMER $\bar{x}$
Total CO_2	(μmoles/l)	350 - 700	443.833
Cl^-	(mg/l)	<1 - 1.2	<1
$SO_4^=$	(mg/l)	2.7 - 4.0	3.783
Si	(mg/l)	0.74 - 1.08	0.895
Total anions	(meq/l)	0.464- 0.860	0.624
Na	(mg/l)	0.72 - 1.24	1.1033
K	(mg/l)	0.41 - 0.80	0.623
Mg	(mg/l)	2.71 - 3.38	3.058
Ca	(mg/l)	7.94 - 11.7	9.437
Total cations	(meq/l)	0.692- 0.9038	0.795
Mn	(mg/l)	0.01 - 0.03	0.018
Total Fe	(mg/l)	0.07 - 0.23	0.1367
NO_3-N	(μg/l)	2. - 9.	6.0
TDN	(μg/l)	230. - 480.	380.
Susp N	(μg/l)	50. - 190.	98.
TDP	(μg/l)	8. - 19.	13.8
Susp P	(μg/l)	11. - 18.	13.67
Chl a	(μg/l)	2.2 - 6.0	4.30
Cond.		60. - 70.	62.67
pH		7.7 - 8.0	7.85
TDS	(μg/l)	30. - 50.	48.0
TSS		<10	<10
Susp C	(μg/l)	660. - 1020.	768.

STATION 10

		RANGE	SUMMER $\bar{x}$	YEARLY $\bar{x}$
Total CO_2	(µmoles/l)	255. - 860	602.767	573.125
Cl^-	(mg/l)	1. - 1.33	1.055	1.041
$SO_4^=$	(mg/l)	3. - 5.	4.000	4.063
Si	(mg/l)	0.895- 1.650	0.889	1.039
Total anions	(meq/l)	0.482- 1.103	0.820	0.787
Na^+	(mg/l)	1.32 - 3.28	2.423	2.393
K^+	(mg/l)	0.917- 1.320	1.082	1.138
Mg^{++}	(mg/l)	2.78 - 4.385	3.428	3.567
Ca^{++}	(mg/l)	7.07 - 15.40	8.273	9.304
Total cations	(meq/l)	0.713- 1.218	0.829	0.899
Mn	(mg/l)	0.01 - 0.043	0.021	0.023
Total Fe	(mg/l)	0.04 - 0.13	0.086	0.081
NO_3-N	(µg/l)	4.0 - 63.0	11.000	19.000
TDN	(µg/l)	230. - 317.	279.500	279.750
Susp N	(µg/l)	53. - 130.	87.167	83.143
TDP	(µg/l)	8. - 20	10.667	12.625
Susp P	(µg/l)	7. - 16.	11.800	10.571
Chl a	(µg/l)	0.6 - 7.8	4.717	4.130
Cond		69. - 92.	77.000	79.250
pH		7.7 - 7.9	7.800	7.743
TDS	(µg/l)	24. - 69.	65.800	57.423
TSS	(µg/l)	<10	<10	<10
Susp C	(µg/l)	537. -1300.	664.667	762.875

STATION 20

		RANGE	SUMMER $\bar{x}$	YEARLY $\bar{x}$
Total CO_2	(µmoles/l)	270. - 800.	558.153	527.365
Cl^-	(mg/l)	< 1 - 1	1.0	1.0
$SO_4^=$	(mg/l)	3. - 6.	4.0	4.0
Si	(mg/l)	0.55 - 1.74	0.823	1.025
Total anions	(meq/l)	0.471- 1.010	0.594	0.741
Na^+	(mg/l)	2.10 - 3.29	2.313	2.511
K^+	(mg/l)	0.89 - 1.31	1.033	1.089
Mg^+	(mg/l)	2.82 - 4.42	3.302	3.561
Ca^+	(mg/l)	7.31 - 10.20	7.940	8.490
Total cations	(meq/l)	0.725- 1.047	0.795	0.853
Mn	(mg/l)	0.01 - 0.05	0.020	0.019
Total Fe	(mg/l)	0.01 - 0.270	0.076	0.093
NO_3-N	(µg/l)	4. - 81.	9.500	20.125
TDN	(µg/l)	242. - 390.	279.830	299.250
Susp N	(µg/l)	52. - 92.	78.500	
TDP	(µg/l)	7. - 23.	9.333	12.375
Susp P	(µg/l)	5. - 12.	10.000	8.714
Chl a	(µg/l)	1.05 - 8.7	4.875	4.320
Cond		68. - 90.	73.500	77.375
pH		7.7 - 8.0	7.82	7.80
TDS	(µg/l)	48. - 93.	59.17	67.25
TSS	(µg/l)	<10	<10	<10
Susp C	(µg/l)	510. - 865.	652.000	673.380

STATION 30

		RANGE	SUMMER $\bar{x}$
Total CO_2	(μmoles/l)	308. - 743.	553.00
Cl^-	(mg/l)	4. - 2.	1.17
$SO_4^=$	(mg/l)	2. - 5.	3.67
Si	(mg/l)	0.37 - 0.97	0.68
Total anions	(meq/l)	0.467- 0.926	0.74
Na^+	(mg/l)	2.19 - 2.58	2.32
K^+	(mg/l)	0.94 - 1.10	1.02
Mg^+	(mg/l)	3.05 - 3.45	3.28
Ca^+	(mg/l)	7.68 - 8.63	8.17
Total cations	(meq/l)	0.782- 0.850	0.802
Mn	(mg/l)	0.01 - 0.05	0.033
Total Fe	(mg/l)	0.03 - 0.11	0.077
NO_3-N	(μg/l)	< 5. - 18.	9.000
TDN	(μg/l)	233. - 330.	257.667
Susp N	(μg/l)	53. - 105.	75.333
TDP	(μg/l)	7. - 14.	10.333
Susp P	(μg/l)	7. - 13.	10.200
Chl a	(μg/l)	1.5 - 8.2	4.217
Cond		71. - 77	73.833
pH		7.7 - 7.9	7.82
TDS	(μg/l)	40. - 90	59.500
TSS	(μg/l)	<10	<10
Susp C	(μg/l)	510. - 860.	674.330

STATION 40

	RANGE	SUMMER $\bar{x}$	YEARLY $\bar{x}$
Total CO_2	265 - 775	583.167	593.25
Cl^-	1. - 2.	1.167	1.125
SO_4	4. - 5.	3.857	4.625
Si	0.31 - 1.48	0.444	0.707
Total anions	0.489- 0.964	0.710	0.6793
Na^+	2.27 - 3.04	2.441	2.530
K^+	0.95 - 1.30	1.011	1.078
Mg^+	3.20 - 4.21	3.557	3.710
Ca^+	8.50 - 10.72	9.107	9.405
Total cations	0.859- 0.979	0.891	0.906
Mn	0.01 - 0.05	0.030	0.026
Total Fe	0.04 - 0.21	0.066	0.089
NO_3-N	3. - 74.	9.167	18.630
TDN	220. - 324.	265.333	273.875
Susp N	45. - 90.	68.833	61.86
TDP	7. - 23.	10.333	13.125
Susp P	5. - 12.	9.400	8.142
Chl a	1.3 - 4.6	2.650	2.200
Cond	76. - 90.	79.500	82.125
pH	7.6 - 8.0	7.880	7.84
TDS	50. - 110.	67.500	68.500
TSS	< 10	< 10	< 10
Susp C	520. - 820	670.833	656.875

STATION 50

	RANGE	SUMMER $\bar{x}$	YEAR
Total CO_2	275. - 870.	638.333	619.
Cl^-	< 1 - 1	1	1
$SO_4^=$	3. - 5.	3.833	4.
Si	0.35 - 0.64	0.492	0.
Total anions	0.445- 1.061	0.797	0.
Na^+	1.60 - 2.47	1.635	1.
K^+	0.61 - 1.00	0.678	0.
Mg^+	3.03 - 4.62	3.442	3.
Ca^+	10.47 - 12.40	11.695	11.
Total cations	0.894- 1.124	0.906	0.
Mn	0.01 - 0.05	0.040	0.
Total Fe	0.02 - 0.13	0.077	0.
NO_3-N	3. - 21.	8.833	10.
TDN	190. - 317.	263.167	260.
Susp N	16. - 80.	61.833	51.
TDP	5. - 35.	10.167	14.
Susp P	2. - 11.	6.833	7.
Chl a	0.15 - 4.1	2.625	2.
Cond	81. - 95.	82.000	85.
pH	7.7 - 8.0	7.84	7.
TDS	50. - 96	61.667	67.
TSS	<10	<10	<10
Susp C	509. - 915.	686.333	643.

STATION 60

	RANGE	SUMMER $\bar{x}$	YEARLY
Total CO_2	649. -1522.	1110.667	1056.125
Cl^-	1. - 1.	1.	1.
$SO_4^=$	3. - 8.	4.000	4.125
Si	1.30 - 2.34	1.588	1.565
Total anions	0.806- 1.839	1.127	1.318
Na^+	1.93 - 2.51	1.982	2.101
K^+	0.812- 1.177	0.889	0.949
Mg^+	3.26 - 7.02	4.859	5.286
Ca^+	18.7 - 24.4	20.628	21.400
Total cations	1.480- 1.932	1.571	1.643
Mn	0.01 - 0.06	0.03	0.03
Total Fe	0.05 - 0.22	0.085	0.101
NO_3-N	< 1 - 26.	10.167	9.00
TDN	198. - 320.	252.00	247.750
Susp N	3. - 56.	47.667	38.625
TDP	8. - 18.	11.333	12.750
Susp P	3. - 10.	8.000	6.571
Chl a	0.2 - 3.0	2.417	2.157
Cond	131. - 164.	136.167	142.250
pH	8.0 - 8.2	8.08	8.063
TDS	44. - 122.	93.000	87.750
TSS	<10	<10	<10
Susp C	301. - 560.	480.500	468.000

Table 2.3.4.5. Comparison of some upper Churchill River and Shield lakes.

	Precambrian Shield Lakes							
	Reindeer[1]	Wollaston[2]	Cree[4]	MacKay[5]	Contact[5]	Little Deer[5]	Hebden[5]	McIntosh[6]
pH surface	7.2	7.2	7.0	7.3	7.3	7.3	7.4	7.1
bottom	6.8	6.8	6.5	6.8	6.7	6.8	6.7	6.6
Cl ppm	0.3	nil	1.4	14	10	10	3	nil
SO4 ppm	2.0	0.6	0.6	2.0	3.0	3.0	3.0	nil
Si ppm	2.0	0.5	0.4	3.6	1.8	2.8	4.5	1.5
Na ppm	1.8	0.42	2.8	2.2	1.8	3.5	2.4	5
K	1.1	-	-	0.8	1.7	2.5	1.3	5
Mg	1.3	7.5	1.0	1.6	5.0	4.1	2.4	1
Ca	2.5	3.6	2.6	5.8	8.0	2.6	4.8	4
Secchi	7.0	6.8	7.8	5.1	5.2	3.8	3.7	4.1
Highest mean temp °C	13	11.1	14.1	14.5	14.8	18	14.4	18.5
Max bottom	6.5	5.8	10.1	-	-	-	-	-
O_2 mg/1	8.3	9.7	9.3	6.3	6.2	5.8	6.0	-
HCO_3 ppm	15.3	23.6	24.6	29	35	32	37	20

Table 2.3.4.5. cont.

	Churchill River Lakes			
	Frobisher[3]	Churchill[3]	Trout[6]	SIL at Station 20[7]
pH surface	8.1	8.1	7.9	7.8
bottom	7.6	7.5	6.9	7.8
Cl ppm	3.7	3.5	nil	1.0
SO_4 ppm	4.4	5.8	nil	4.0
Si ppm	4.5	2.8	0.8	1.0
Na ppm	1.4	2.3	<5	2.5
K	-	-	<5	1.1
Mg	8.0	10.8	6	3.6
Ca	14.6	25.9	11	8.5
Secchi	1.7	2.1	3.6	1.4
Highest mean temp °C	18	19.2	18.6	17.6
Max bottom	7	6	-	sat[7]
HCO_3 ppm	67.6	121	60	28

1. After: Armstrong and Schindler, 1971; Rawson, 1959.
2. After: Armstrong and Schindler, 1971; Rawson, 1959; Rawson, 1959.
3. After: Rawson, 1957; Rawson, 1960.
4. After: Armstrong and Schindler, 1971; Rawson, 1959; Rawson, 1960.
5. After: Koshinsky, 1965.
6. After: Koshinsky, 1971.
7. Southern Indian Lake, at station 2, is usually oxygen saturated.

Table 2.3.4.6. Spatio-temporal determination of nitrate (g/1) in Southern Indian Lake, 1972-73. Values underlined represent peak summer concentrations.

Station	June 1	June 21	July 10	August 10	August 21	Sept 12	October 4	December 10	March 28
09	18	17	20	16	7	5	9	-	41
10	-	4	25	9	8	14	5	21	63
20	-	4	21	9	7	6	6	23	77
30	-	2	17	8	12	4	<5	-	-
40	-	3	26	9	8	8	<5	18	74
50	-	3	21	7	7	7	6	12	19
60	-	6	26	6	8	7	9	7	-
49B	13	5	33	9	8	5	8	-	75

2.3.5. CHEMICAL ANALYSES, SYNOPTIC STATIONS

The main chemistry stations were located at central locations within the regions set up by the Fisheries-Limnology component (Cleugh, Ayles, and Baxter, 1974). The synoptic chemistry stations were located throughout the lake to compare the water quality of the remainder of the lake with the chemical analysis of the main stations (see map in Appendix IV, p. 157 for locations).

Fifty-eight stations were sampled in early July and late August. The analyses are reported in Appendix IV. Some of the stations are located in bays or near streams and show chemical features decidedly different from the main stations. By and large, however, the main stations appear to be representative of the larger regions.

Regions 5 and 6, showed marked differences from the main basin of Southern Indian Lake. Region 6 had the highest concentrations of magnesium, calcium, silicon, suspended phosphorus, total dissolved solids, suspended solids, and highest conductivity; and the lowest concentration of chlorophyll. Region 5 had the lowest concentration of potassium and sodium, a very low concentration of silicon, and a high concentration of calcium. These differences were also evident at the main stations.

2.3.6. NUTRIENT LOADING

Nutrients reported as concentrations are not meaningful in themselves as biological populations generally maintain them at low levels. Nutrient loading rates (Vollenweider, 1968) must be determined for the system as a whole as these values are meaningfully comparable from one lake to another. Loading is the rate of delivery to a lake. The effect any loading rate has on a system will depend on the volume of water through which the loading is distributed (dilution).

Incomplete monthly data dictated extrapolation of chemical concentrations for the months of January, April, May and November. Estimated concentrations and loading at Opachuanau Rapids, into Region 5, and by the four major streams (as characteristic of local drainage) are presented in Tables 2.3.6.1 to 2.3.6.7. Estimated concentrations and loading after impoundment and diversion are presented in Tables 2.3.6.8 and 2.3.6.9. Loading was computed as follows:

$$\text{Loading (g/sec)} = \frac{\text{Discharge (cfs)}}{1000} \times \frac{28.3\ \text{l}}{1\ \text{cfs}} \times \frac{\text{mg(nutrient)}}{\text{l}}$$

To make loading rates and the effects of the rates comparable from lake to lake results are generally expressed per square meter of lake surface and plotted against mean depth (Vollenweider, 1968).

Annual phosphorus loading of Region 5 from Waddie River is computed as follows:

$$L = \frac{4.6 \text{ kgms}}{208 \text{ km}^2} = 0.022 \text{ gms P/m}^2\text{/yr}$$

where area is 208 km^2, and loading of P is 4.6 kgms per year (see Table 2.3.6.5). This loading is derived by assuming that the Waddie is the only important nutrient source to region 5. As there is exchange between regions 4 and 5 the figure may be too low by as much as 25%.

Plotting on Figure 2.3.6.1 indicates Region 5 was oligotrophic in 1972-73. This figure modified from Vollenweider is based on the estimated trophic status of numerous lakes primarily in Europe and temperate North America with different loading and morphometric characteristics. It demonstrates the principle that low areal loading or great volume (large mean depth) will result in oligotrophic conditions while high loading in a small volume will yield eutrophy.

Total phosphorus loading from all sources in Southern Indian Lake, for 1972-73, is 795.6 x 10^6 gms/year (based on the Churchill River discharge and an additional 4,000 cfs of local discharge), which makes the loading on an areal basis 0.35 gms P/m^2 (where total area is 2,253 x $10^6 m^2$ and mean depth 9.2 m). If regions 5 and 6 which do not receive significant loading from the Churchill River are eliminated, the annual loading by the Churchill to the main lake would be 0.53 gms P/m^2. Plotting on Figure 2.3.6.1 indicates the lake would be expected to be mesotrophic to eutrophic depending upon the assumptions made. Phytoplankton standing crop and primary production estimated in Hecky (1974) indicate that the different lake regions are oligotrophic to mesotrophic.

When compared with other lakes for which loading data are available, Southern Indian Lake appears to be somewhat less productive than might be expected from nutrient loading considerations alone. The discrepancy between nutrient loading and trophic state will be discussed in section 3. A discussion of nutrient loading after impoundment and diversion is given in section 2.3.7.

Table 2.3.6.1. Estimated monthly concentrations of nutrients at station 09. (Opachuanau Rapids). Asterisks indicate months for which concentrations were determined by extrapolation.

		Jan*	Feb	Mar	Apr*	May*	June	July	Aug	Sept	Oct	Nov*	Dec
Flow x10^3	cfs	28	26	24	24	30	40	37	38	34	33	32	29
TDN	µg/l	330	450	320	320	320	330	380	300	300	300	290	280
Susp N	µg/l	40	40	30	30	30	65	150	190	80	70	50	40
NO_3	µg/l	30	41	85	40	30	18	20	12	9	9	12	20
Susp P	µg/l	5	5	4	5	8	12	11	16	12	12	8	5
TDP	µg/l	25	25	19	20	16	12	12	8	8	18	20	20
Si	mg/l	1.4	1.4	1.6	1.5	1.4	1.0	1.0	0.75	1.3	1.3	1.4	1.4

Table 2.3.6.2. Estimated loading, station 09, 1972-73.

	Winter $\bar{x}D = 27.6$		Summer $\bar{x}D = 36.5$		Year D = 31.3	
	Mean	Loading gms/sec	Mean	Loading gms/sec	Yearly mean	Loading gms/sec
TDN	330	258	322	322.6	326.6	289.6
Susp N	37	28.9	111	114.7	74	65.6
NO_3	36.8	28.7	13.6	14.05	25.2	22.35
Susp P	5.7	4.45	12.6	13	9.1	8.06
TDP	20.7	16.2	11.6	11.98	16.1	14.27
Si	1.4	1,090.	1.07	1,105	1.25	1,108
Total P	26.4	20.6	24.2	24.99	25.3	22.4
Total N	403.8	287	446.6	437	425.2	355

Abbreviations: D = discharge; $\bar{x}$ = mean; gms = grams; sec = second

Table 2.3.6.3. Estimated mean monthly concentrations of nutrients at station 49B (Missi Rapids). Asterisks indicate extrapolated values. Unites of concentrations as Table 2.3.6.1.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Flow x10^3	33	31	29	28	28	35	40	41	42	39	35	35
TDN	350	425	420	420	410	400	360	220	250	260	270	280
Susp N	40	32	61	70	80	95	100	140	70	70	60	50
NO_3	30	40	75	40	20	9	9	9	8	8	10	20
Susp P	4	4	4	4	4	10	8	8	8	7	6	5
TDP	25	28	35	30	14	14	12	6	9	12	15	20
Si	1.4	1.5	1.5	1.5	1.5	0.5	0.4	0.4	0.4	0.3	0.8	1.2

Table 2.3.6.4. Estimated unloading, station 49B, 1972-73. Units of concentration as in Table 2.3.6.1.

	Winter D = 32		Summer D = 38		Yearly D = 35	
	Conc.	Unloading gms/sec	Conc.	Unloading gms/sec	Conc.	Unloading gms/sec
TDN	368	333	300	322.6	334	327.6
Susp N	56	50.7	95	102	75.5	74
NO_3	33	29.8	9	9.6	21	20.6
Susp P	4.4	3.98	8.2	8.8	6.3	6.18
TDP	22	19.9	10.6	11.4	16.3	16
Si	1.4	1,268	0.4	430	0.9	880
Total P	26.4	23.9	18.8	20.2	22.6	22.1
Total N	457	413	404	434	430	421.8

Abbreviations: Conc.

Table 2.3.6.5. Estimated loading to Region 5 from Waddie River, 1972-73. Units of concentrations as in Table 2.3.6.1.

	Summer conc.	Loading gms/sec	Winter conc.	Loading gms/sec	Yearly conc.	Loading gms/sec
Flow	290	-	-	-	-	-
TDN	384	3.15	430	2.25	407	2.7
NO_3	9.8	0.08	44	0.23	26.9	0.179
Susp N	98	0.8	60	0.31	79	0.525
Susp P	9	0.07	5	0.025	6.5	0.043
TDP	11	0.09	20	0.104	15.5	0.103
Si	0.82	6.73	1.64	8.6	1.23	8.2

Table 2.3.6.6. Loading by four major streams flowing into Southern Indian Lake, 1972-73. Units of concentrations as in Table 2.3.6.1.

	Average conc.	Loading gms/sec
Flow	4,000	-
TDN	390	44.15
NO_3	-	-
Susp N	114	12.9
Susp P	13	1.47
TDP	12	1.36
Si	0.67	75.8

Table 2.3.6.7. Total yearly loading by the Churchill River (09) and local drainage (other) and output at Missi Rapids (49B), Southern Indian Lake, 1972-73. Difference = Input-Output. Units, gm/sec.

	09	Other	Total	49B	Difference
TDN	289.6	44.15	333.65	327	3.65
Susp N	65.6	12.9	79.6	74	5.6
NO_3	22.35	-	-	20.6	-
Susp P	8.06	1.47	9.53	6.18	3.35
TDP	14.27	1.36	15.63	16	-.37
Si	1,108	75.8	1,183.8	880	303.8
Total P	22.4	2.83	25.23	22.1	3.13
Total N	355	57	412	401	11

Table 2.3.6.8. Estimated mean monthly concentrations of nutrients at station 20 after impoundment and diversion. Flow is the estimated transport to the lower lake after diversion. Units as in Table 2.3.6.1.

	Jan*	Feb	Mar	Apr*	May*	June	July	Aug	Sept	Oct	Nov*	Dec
Si	1.6	1.5	1.5	1.3	0.7	0.55	0.78	0.92	0.92	0.95	1.74	1.6
NO_3	30	41	77	30	10	4	22	7	7	8	10	20
TDN	410	450	363	310	290	283	242	270	292	310	340	390
Susp N	45	36	40	45	50	52	87	85	80	75	65	55
Susp P	5	5	5	5	6	7	-	11	12	8	6	5
TDP	25	25	25	20	15	10	9	8	7	15	17	20
Flow	1,500	0	0	0	0	4,000	9,500	10,500	11,500	8,500	6,500	3,000

Table 2.3.6.9. Estimated loading, Southern Indian Lake, below Region 2, after impoundment and diversion

	Summer mean	Loading gms/sec	Winter mean	Loading gms/sec	Yearly mean	Loading gms/sec
Flow	8,500	-	2,000	-	5,250	-
NO_3	9.6	2.3	31	1.3	18.9	2.4
TDN	279	67	364	15.5	328	41.7
Susp N	75.8	18.2	48	2.03	59.6	7.6
Susp P	9.5	2.3	5.3	0.22	6.8	0.87
TDP	9.8	2.4	21	0.89	16.3	2.07
Si	0.82	197	1.42	60	1.16	147
TP	19.3	4.6	26.3	1.12	23.1	2.9
TN	354.8	85.3	412	17.5	387.6	49.4

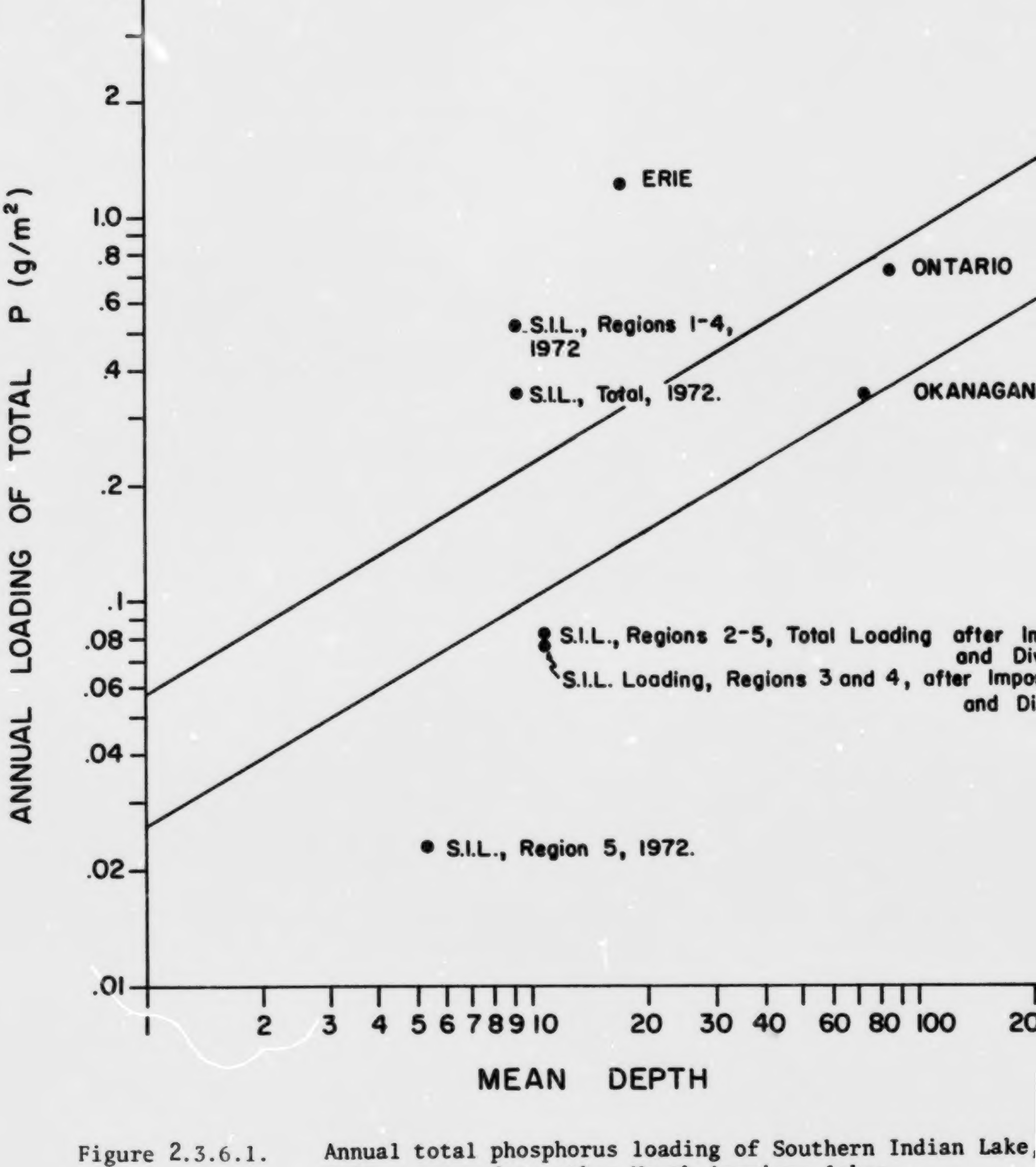

Figure 2.3.6.1. Annual total phosphorus loading of Southern Indian Lake, 1972, compared to other North American lakes.

RETENTION AND COMPARISON OF INFLOW (STATION 09) AND OUTFLOW (STATION 49B) OF SOUTHERN INDIAN LAKE

Retention is the excess of input into a lake over the removal at the outflow (Lerman, 1972).

$$\text{Retention} = \frac{\text{Amount introduced - amount removed}}{\text{Amount introduced}} \times 100$$

Nutrients are usually efficiently removed from inflowing waters by algal growth and incorporation into biomass of higher trophic levels. Death of organisms leads to decay and decomposition by microorganisms. Decomposition is generally incomplete and some detrital organic material is trapped in sediments. If regenerative processes are efficient and residen time of water is relatively low, retention will be low and much of the nutrient mass introduced to a system will pass through. Availability of oxygen and temperature affect rates of regeneration while residence time is determined by hydrology and basin morphometry.

The amounts of each nutrient introduced and removed are given in Table 2.3.6.7. The values of retention are given in Table 2.3.6.10.

Table 2.3.6.10. Retention, 1972, Southern Indian Lake

	Inputs		Output	Retention
	Churchill River	Local Drainage	Missi Rapids	
Total phosphorus	22	2.8 g/sec	22 g/sec	12%
Total nitrogen	412	57	401 g/sec	3%
Total silicon	1,108	76	880 g/sec	25%

Phosphorus retention, approximately 14%, is surprisingly low for th size of the lake reflecting inefficient utilization of loading and/ efficient regeneration. The removal of Si results from the activit of diatom populations and the accumulation of siliceous remains whi are relatively insoluble.

2.3.7. IMPACT OF IMPOUNDMENT AND DIVERSION

Previous discussion has shown that the Churchill River determi the chemical composition and nutrient loading rate of Regions 1-4 of Southern Indian Lake and is physically significant (heat gain) to Reg The diversion of 89% of the Churchill River flow through South Bay wi therefore have a significant impact on those regions of Southern Indi Lake downstream from the point of diversion. Regions 1, 2, 5 and 7 f patterns will remain basically similar to pre-diversion, with the exc that half of region two may be affected by a decreased flow similar t that of Region 3. Region 6 will change radically due to increased fl exchange rates for this bay will change from 3.13 years to 12.7 days. The very fast exchange indicates that South Bay will primarily reflec the chemical composition and biological activity of Regions 1 and 2. Diversion may not affect all areas of South Bay equally as water mass formation similar to that in the main lake will occur. The impact on these areas will be discussed below with other effects of impoundmen

The decreased flow from the Churchill River will reduce the nut input into Regions 2, 3, and 4. Based on Table 2.3.6.9 the total annu phosphorus loading from the Churchill River after diversion could be reduced to:

$$\frac{91.5 \times 10^{6} \text{ gms}}{1191.8 \times 10^{6} \text{m}^{2}} = 0.077 \text{ gms/m}^{2}$$

Where Area = 1/2 of Region 2 + Regions 3 + 4 = 1191.8 x 10

Total P = 2.9 gms/sec or 91.5 x 10^6 gms/yr

$\bar{x}$ depth = 10.82 meters

As the trophic state of the present lake is below what might be
from phosphorus loading characteristics, the meaning of this lar
reduction is not entirely clear. After diversion phosphorus loa
these lake areas will still be three times the present loading r
Region 5. The significance of the reduced loading to productivi
discussed in Hecky (1974). Most of this loading will occur in t
as winter drawdown will likely result in a net movement of water
Regions 2, 3, and 4 into the diversion canal at South Bay. As a
lower winter loading, lower nutrient concentrations may be ob
early spring and phytoplankton activity may be reduced.

Local streams will be more significant in regions 3 and 4
diversion. Presently the streams contribute 8.41% of the total
Missi Rapids. After diversion they will contribute 36.81% of th
flow at Missi Rapids. Regions 3 and 4 may expect increased calc
magnesium, specific conductance, total dissolved solids, and col
sodium and potassium decline. As nutrient concentrations are de
by biological activity, estimates on post diversion concentratio
be highly speculative.

All regions of Southern Indian Lake will be affected by wa
quality changes due to inundation. The initial effect of impoun
will be an increase in nutrients from the new littoral zone beca

leaching from the shoreline soils and decaying vegetation. The nutrient release may last for several years and may increase the productivity of lake regions where the flow regime is not altered.

Oxygen levels may be affected in the flooded littoral zone of Southern Indian Lake. Decomposing drowned vegetation may cause anaerobic conditions, especially under the ice. Winter oxygen levels in areas of extensive inundation could become very low as is observed in Kettle Reservoir in inundated areas. If oxygen demand were extreme, Regions 3 and 4 might have reduced oxygen tensions during periods of low or negative flows. Oxygen will likely have a high saturation level in the main basin during summer months due to wind mixing.

2.3.2.8. SUMMARY

1. The large discharge of the Churchill River, 92% of the total outflow at Missi Rapids, ensures that the major ion composition of most of Southern Indian Lake will reflect the river composition. The chemical influence of the Churchill River is analytically evident throughout the main lake basin at stations 10, 20, 30 and 40.

2. Region 5 (north of Sand Point) and Region 6 (South Bay) have chemical compositions distinct from the Churchill River. Local stream drainage is the primary determinant as it is in Region 7 and isolated, inshore areas of Regions 1, 2, 3, and 4.

3. Southern Indian Lake is situated on the Canadian Shield, but glaciolacustrine clays predominate in the area and exert an effect on the water quality of inflowing streams. Local stream flows, 1972-73 constituted 8.41% of the total flow at Missi Rapids. After diversion these chemically distinct streams will contribute 36.81% of the total outflow at Missi Rapids which will have a long-term effect on the chemical environment of Regions 3 and 4 and will give them a composition more similar to Regions 5 and 6.

4. Southern Indian Lake had a 1972-73 annual loading of 0.35 gms P/m^2. After diversion, Regions 3 and 4 will decline from 0.53 gms $P/m^2/yr$ to annual loading of 0.077 gms P/m^2, a reduction of nearly 80%. Diversion will lower the residence time of region 6 from 3.13 years to 12.7 days while greatly increasing nutrient loading.

5. Silicon retention was 25% annually in 1972, and total phosphorus retention was only 12%. Nitrogen retention was negligible. The values are surprisingly low for the size of the lake.

6. Southern Indian Lake is isothermal in summer and winter. Surface temperatures do not exceed 20°C. The Churchill River exerts a warming influence in Region 1 in the spring. Dissolved oxygen ranges from 67-110% saturation. The majority of the lake is near saturation most of the year. The combination of warm bottom temperatures in summer and oxygen saturation in all seasons should favor efficient regeneration by microbial processes.

The lake is relatively untransparent with a Secchi range of 1-2.5 meters. Lowest Secchi depths are observed in the upper lake while Regions 4 and 5 are the most transparent.

7. Impoundment will alter the water chemistry of the entire lake. Nutrient release from inundated soils and vegetation may help to increase productivity. However, the shoreline erosion will increase the lake turbidity decreasing the photosynthetic zone and tending to decrease areal production. Oxygen depletion may occur in the new littoral zone due to decaying vegetation.

2.3.2.9. BIBLIOGRAPHY

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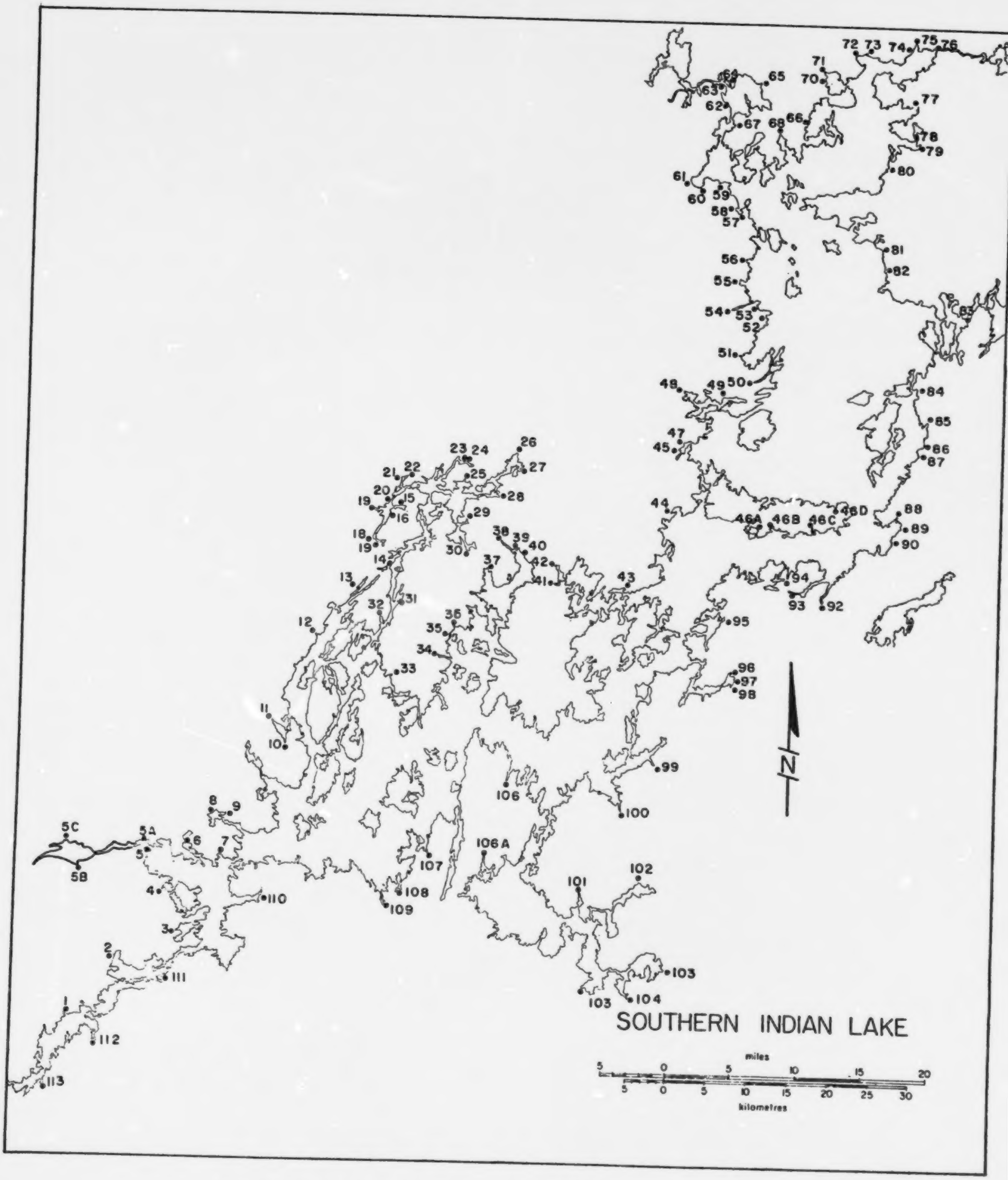
APPENDIX I

Hydrology Southern Indian Lake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Locations of streams measured, 1972.

Table 1. Stream survey. Drainage areas and flows for majority of streams into Southern Indian Lake, see Figure 2.2.1.1 for stream locations.

Stream No.	Drainage area in miles^2	cfs $\bar{x}$ annual
1	22.95	15.49
2	6.36	4.30
3	8.86	5.98
4	16.59	11.20
5	498.40	336.42
5A	401.13	270.76
5B	14.77	9.97
5C	4.55	3.07
6	1.95	1.32
7	4.32	2.91
8	12.05	8.13
9	3.86	2.61
10	4.32	2.91
11	53.41	36.05
12	24.55	16.37
13	4.55	3.07
14	4.09	2.76
15	0.36	0.25
16	0.090	0.060
17	6.82	4.60
18	7.50	5.06
19	734.99	496.12
20	3.41	2.30
21	195.00	131.62
22	2.27	1.53
23	20.00	13.50
24	2.16	1.46
25	1.14	0.77
26	0.82	0.55
27	11.59	7.82
28	5.45	3.68
29	0.91	0.61
30	11.82	7.98
31	2.95	1.99
32	4.09	2.76
33	8.18	5.52
34	10.68	7.21
35	3.41	2.30
36	2.50	1.69
37	1.59	1.07
38	6.36	4.30
39	4.32	2.91
40	3.95	2.67
41	8.41	5.68
42	20.68	13.96
43	2.50	1.69
44	33.86	22.86
45	18.41	12.43
46A	0.95	0.64
46B	0.98	0.66
46C	1.14	0.77
46D	2.23	1.50
47	1.93	1.30
48	239.09	161.38
49	1.36	0.92
50	1.18	0.80
51	7.05	4.76
52	12.05	8.13
53	1.36	0.92
54	9.32	6.29
55	2.50	1.69
56	3.64	2.45
57	1.82	1.23
58	49.77	33.60
59	2.50	1.69

60	1.36	0.92
61	32.27	21.78
62	5.45	3.68
63	908.63	613.32
64	20.45	13.81
65	1.70	1.15
66	3.18	2.15
67	1.82	1.23
68	0.86	0.58
69	0.98	0.66
70	10.68	7.21
71	9.55	6.44
72	8.41	5.68
73	21.59	14.57
74	1.14	0.77
75	21.59	14.57
76	399.54	269.69
77	4.09	2.76
78	7.50	5.06
79	17.50	11.81
80	22.05	14.88
81	7.05	4.76
82	2.27	1.53
83	Churchill River at Missi Falls	
84	2.73	1.84
85	5.00	3.37
86	7.27	4.91
87	7.05	4.76
88	4.55	3.07
89	1.89	1.27
90	18.64	12.58
91	46.36	31.30
92	6.59	4.45
93	6.82	4.60
94	10.45	7.06
95	6.59	4.45
96	10.23	6.90
97	35.00	23.62
98	7.50	5.06
99	70.23	47.40
100	7.05	4.76
101	17.50	11.81
102	36.82	24.85
103	12.05	8.13
104	20.68	13.96
105	10.68	7.21
106	5.00	3.37
106A	5.00	3.37
107	4.55	3.07
108	16.14	10.89
109	12.50	8.44
110	20.00	13.50
111	94.32	63.66
112	51.14	34.52
113	105.00	70.87

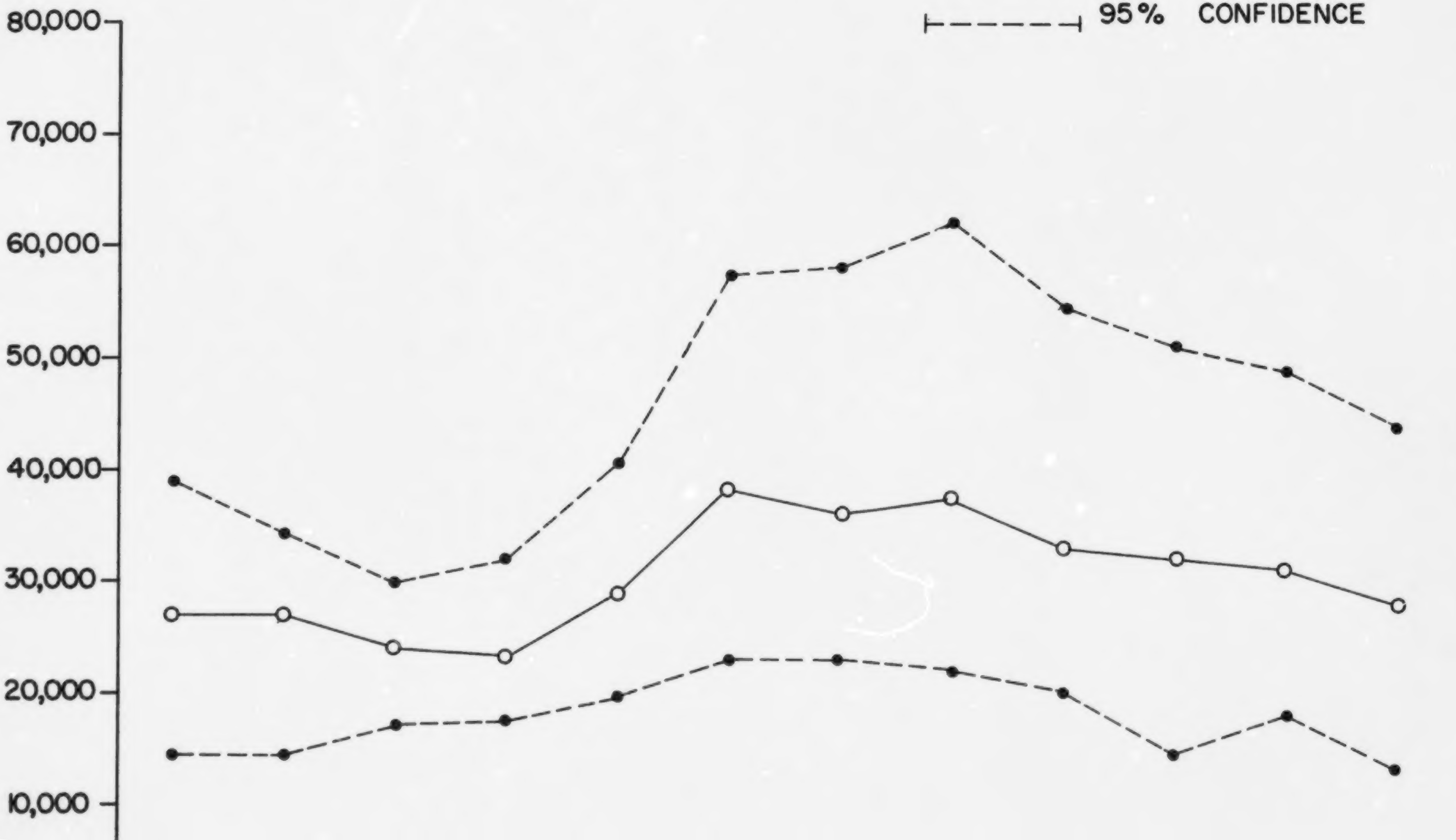
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Figure 1. Leaf Rapids, mean monthly flow.

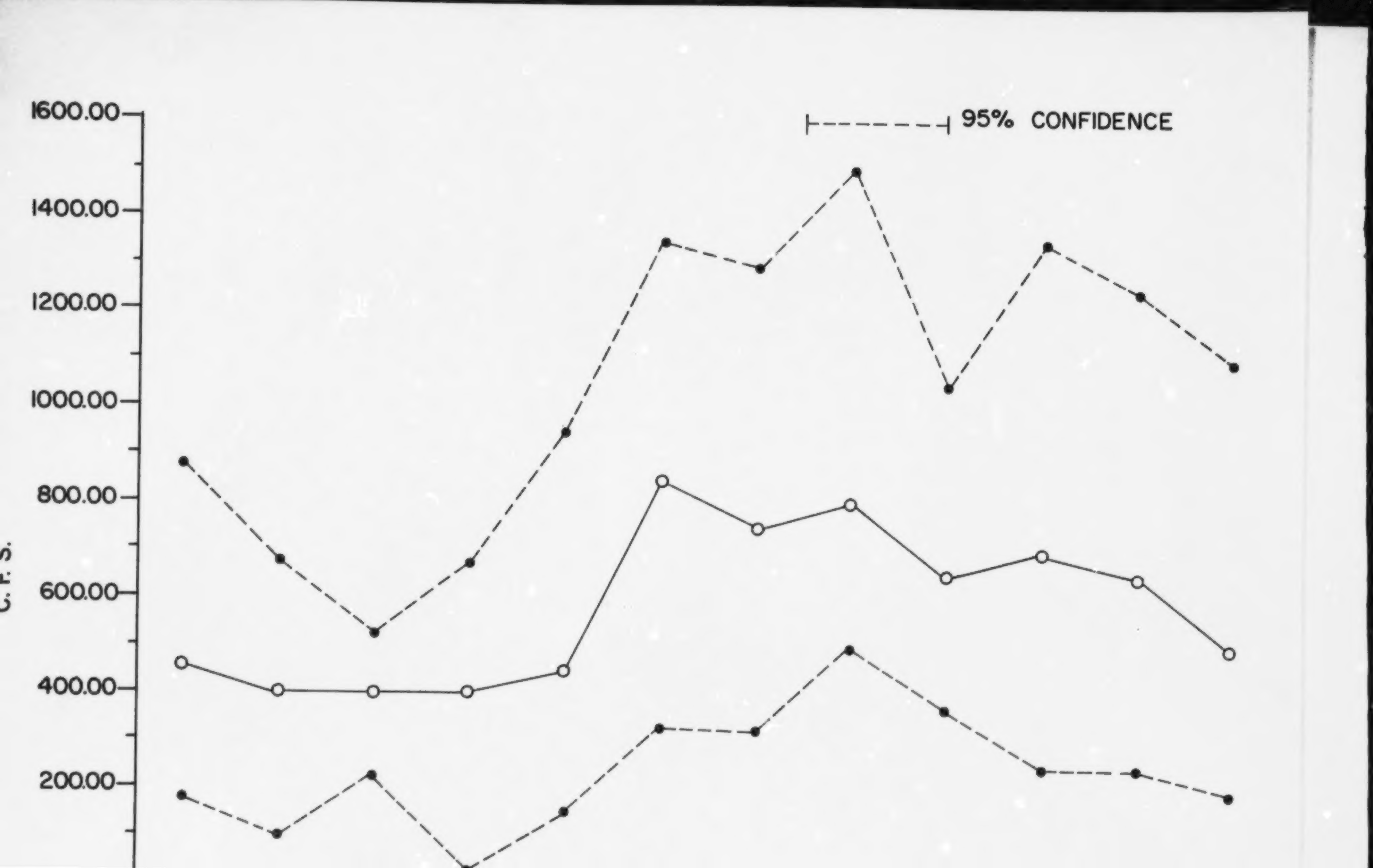
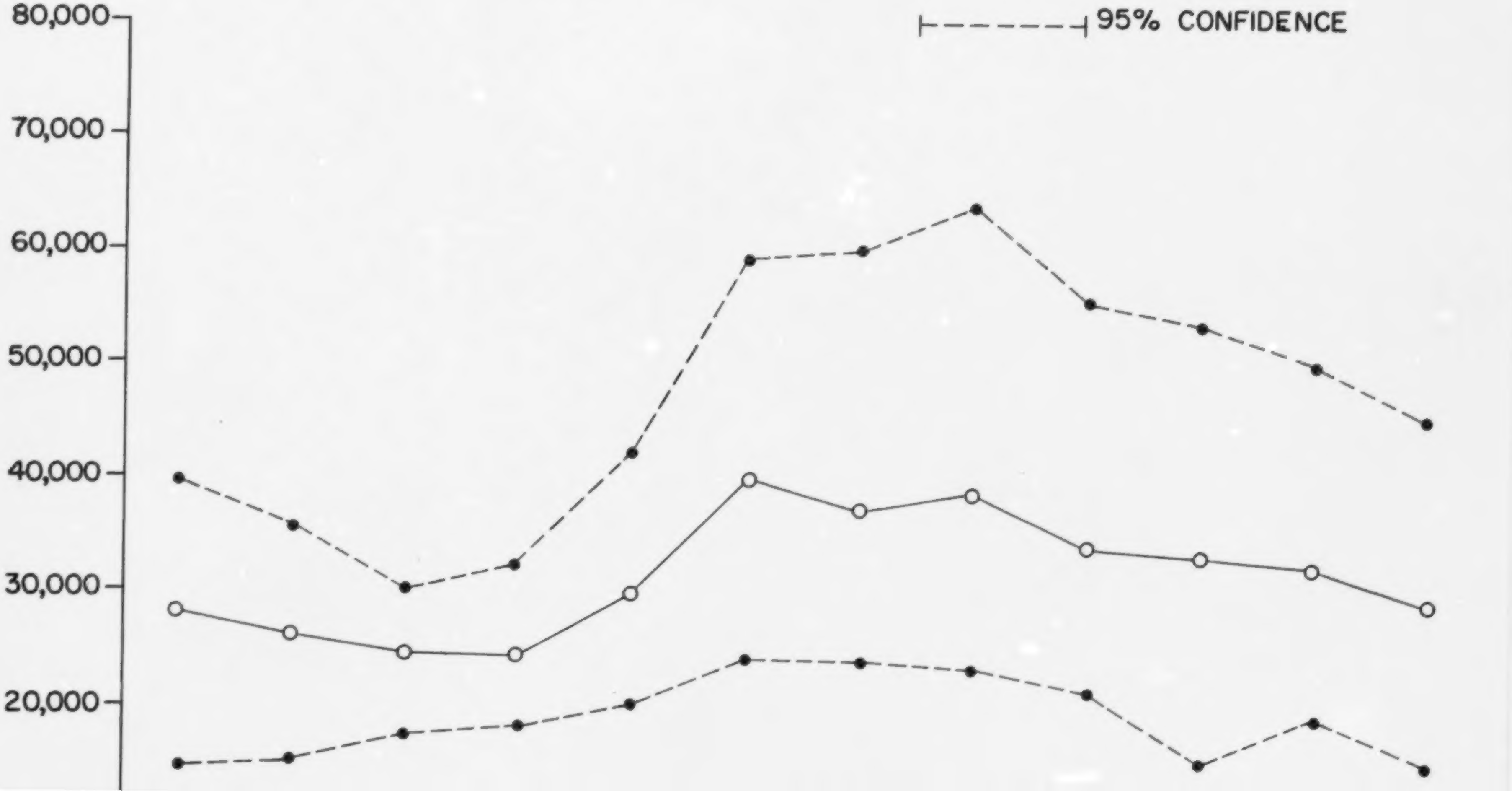


Figure 2. Barrington River, mean monthly flow.



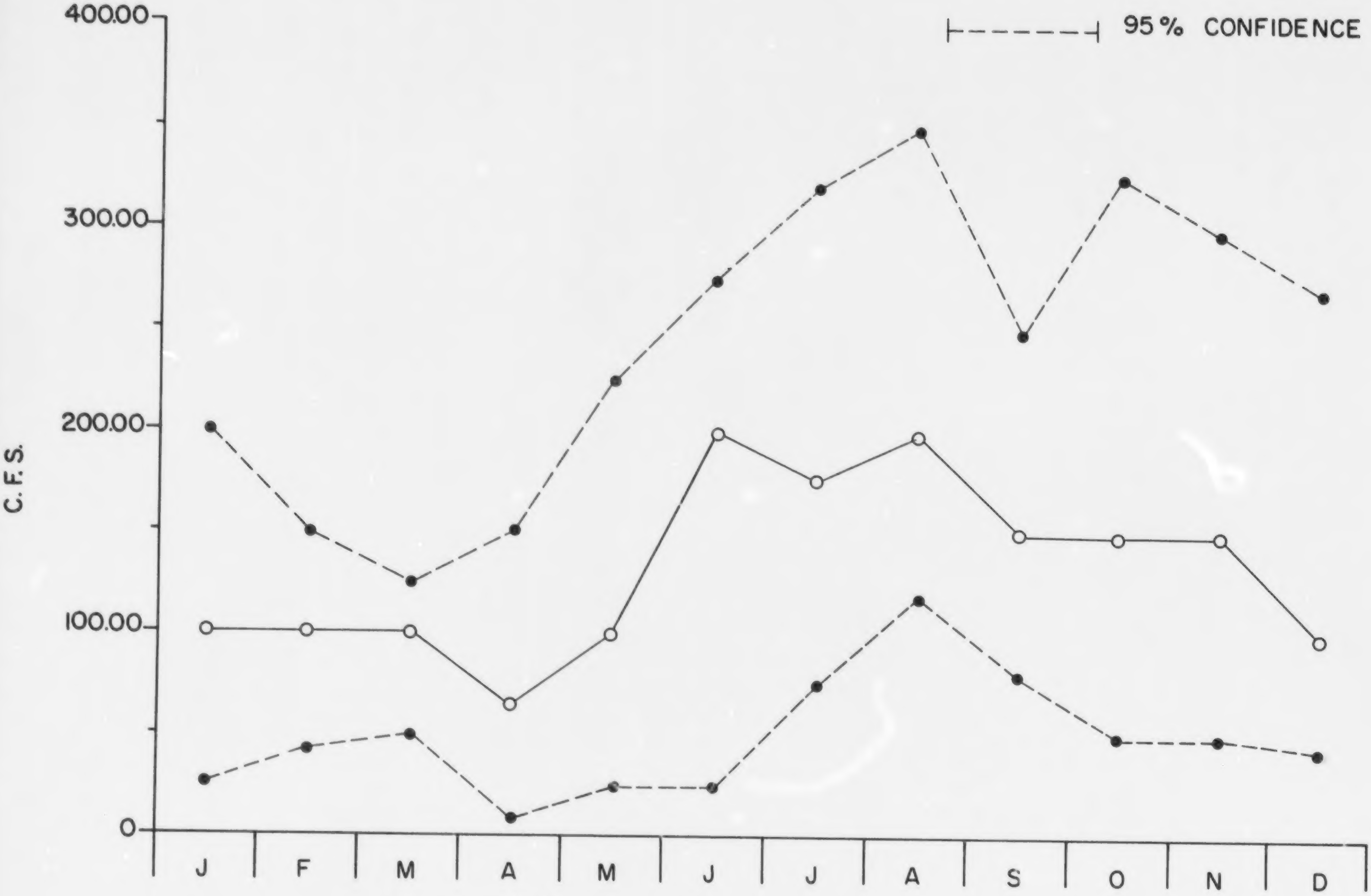


Figure 4. McLeod Lake discharges, mean monthly flow.

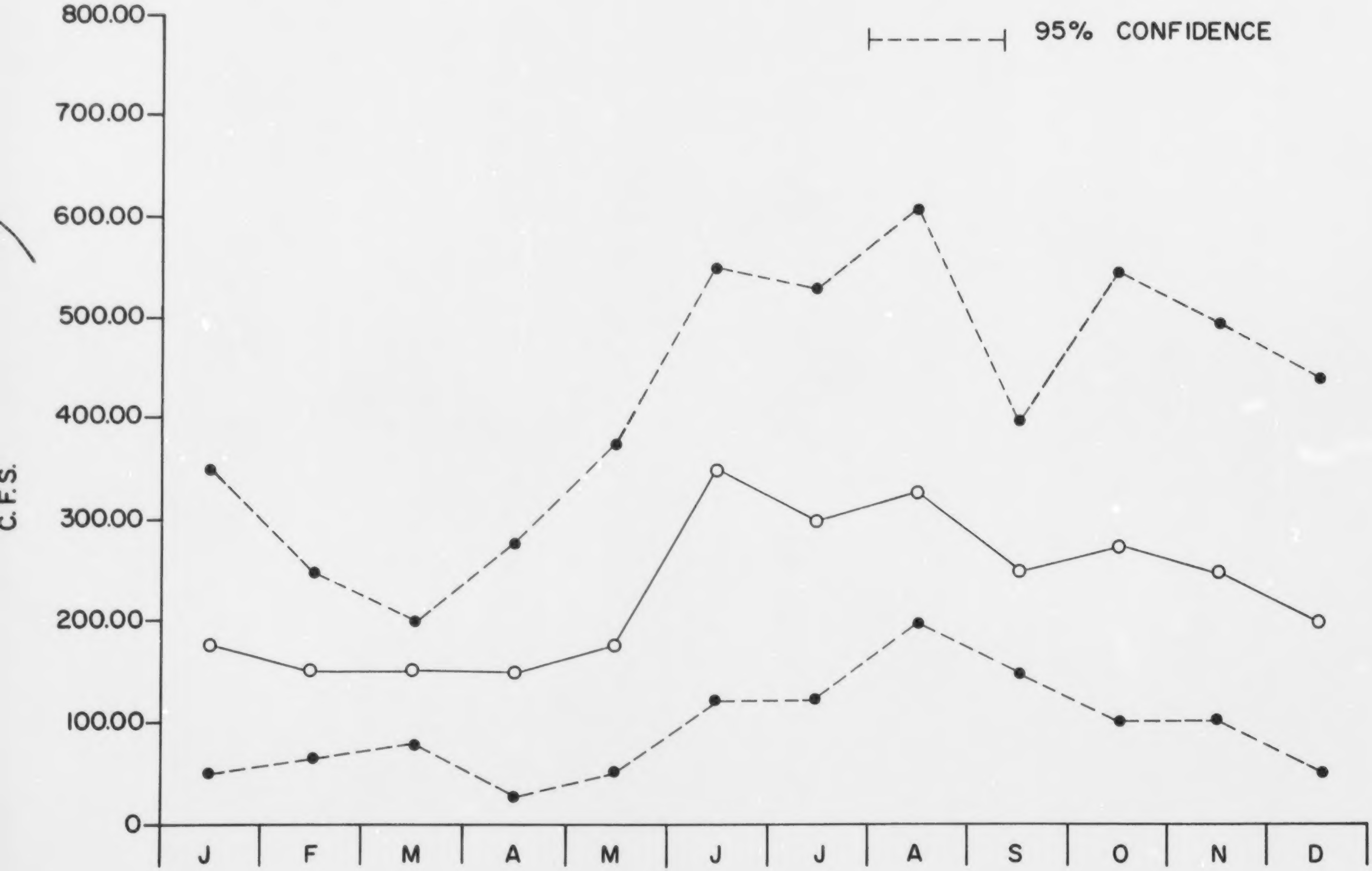


Figure 5. Waddi River, mean monthly flow.

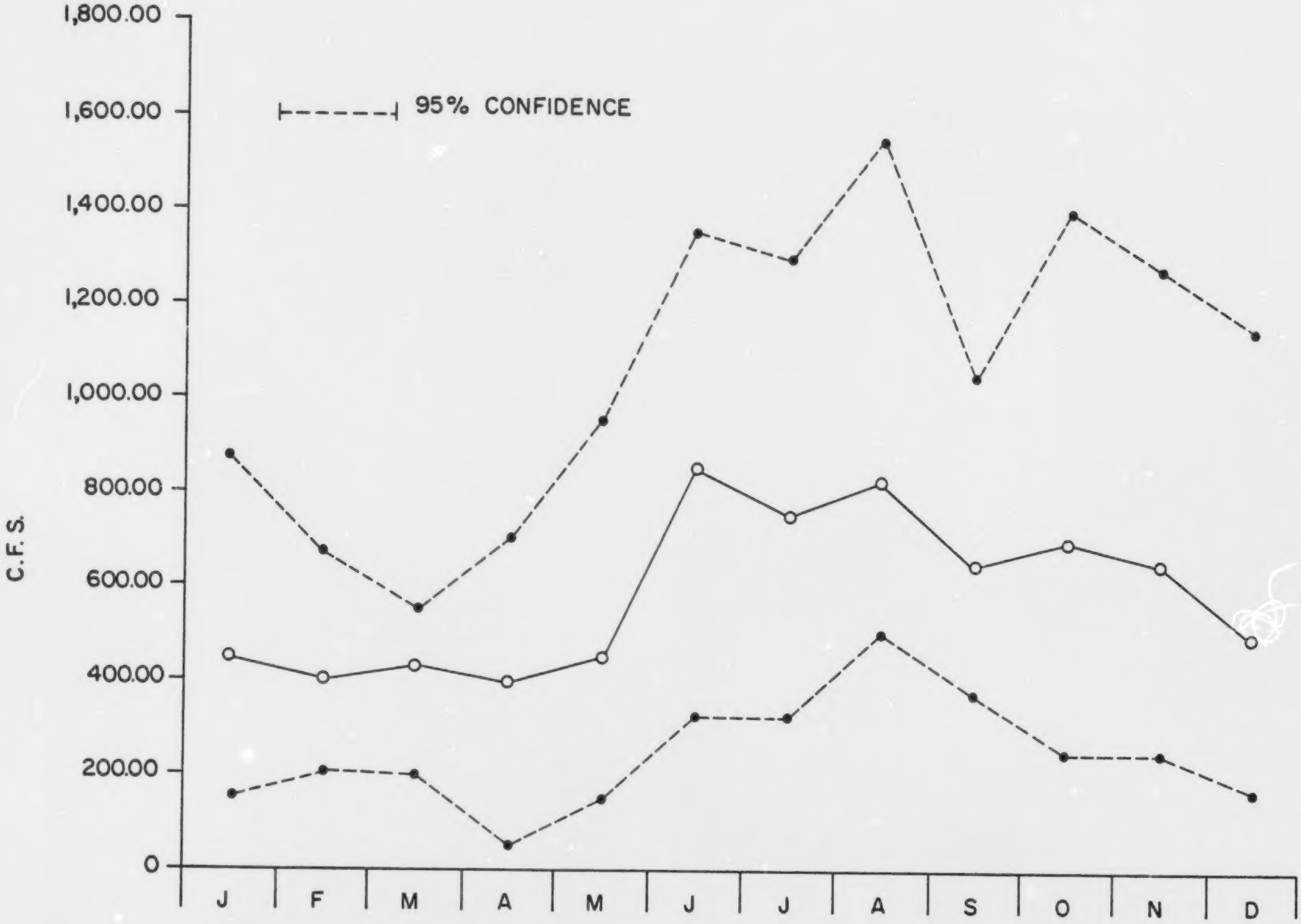
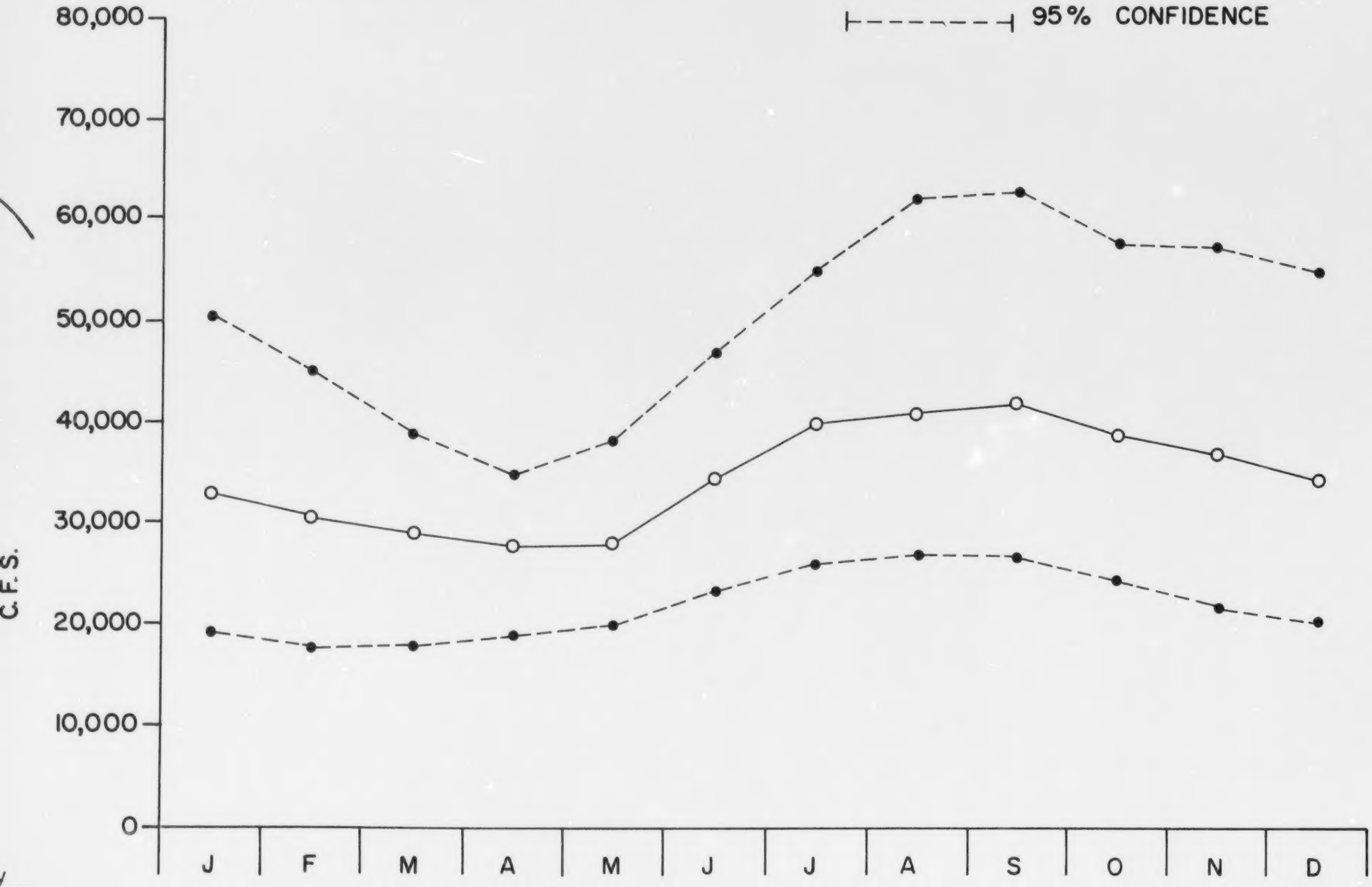


Figure 6. Muskwesi River, mean monthly flow.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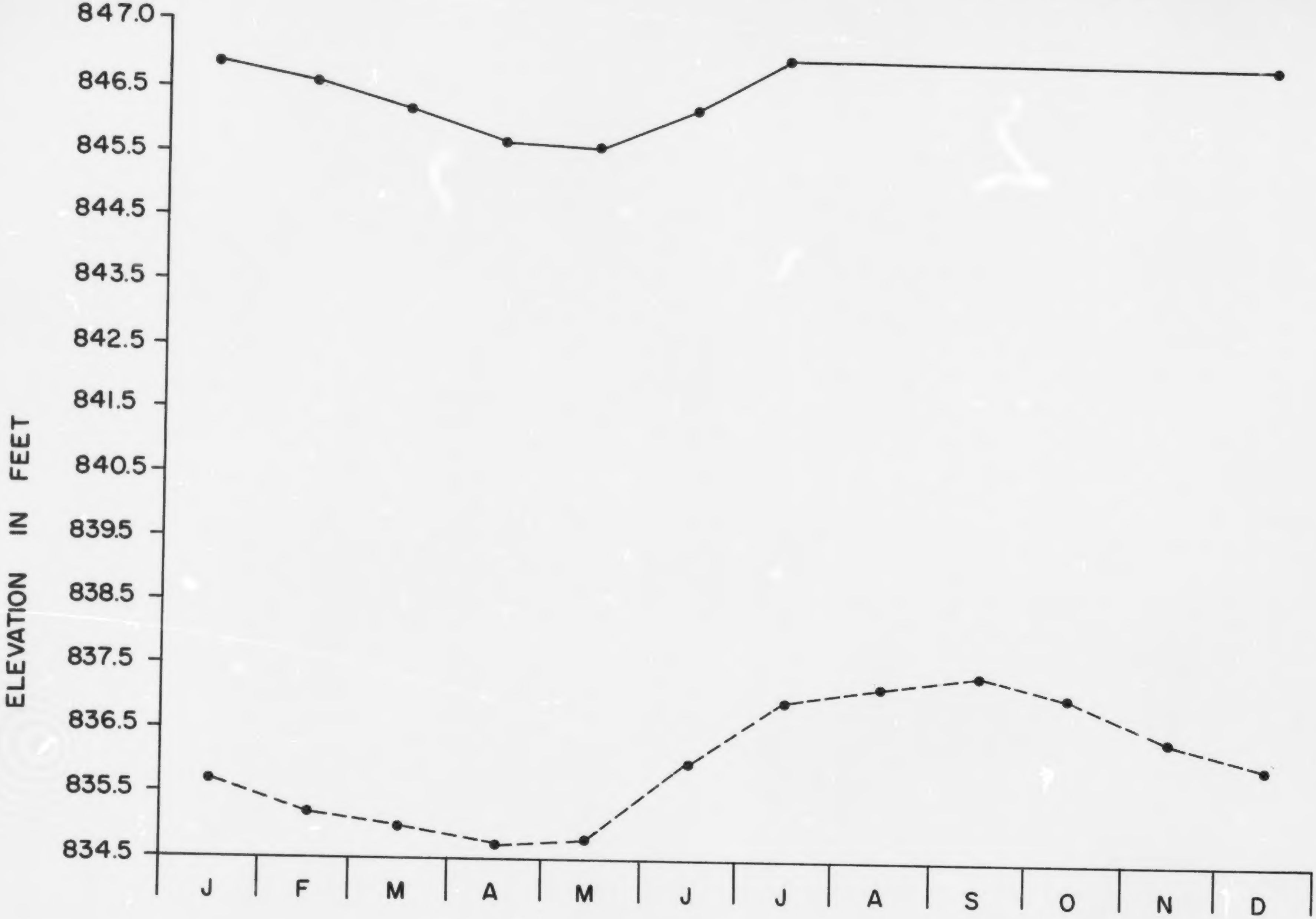


Figure 8. Mean monthly lake levels, Southern Indian Lake.
natural - - - - - regulated ————

APPENDIX II

Chemical Analyses of Main Stations
Southern Indian Lake
1 June 1972 to 28 March 1973.

Table 1. Chemical analyses of water samples from Southern Indian Lake. Locations of stations indicated on Figure 2.3.1.3.

June 1							
Station		09	79	49A	59A	59B	49B
Depth (Meters)		0.5	0.5	0.5	0.5	0.5	0.5
Tot.CO_2	µmoles/1	326	283	228	185	169	194
Cl	mg/1	4.2	1.2	1.0	1.5	1.2	1.5
SO_4	mg/1	4.6	2.7	2.9	2.4	4.1	3.0
Si	mg/1	1.3	0.7	0.7	0.4	1.3	0.7
Na	mg/1	3.5	0.7	0.9	1.2	1.3	2.2
K	mg/1	1.2	0.4	0.4	0.4	0.8	0.9
Mg	mg/1	4.9	3.4	3.1	2.3	2.7	2.8
Ca	mg/1	10.6	11.7	9.8	7.2	7.3	6.5
Mn	mg/1	-	-	-	-	-	-
Fe	mg/1	0.2	0.2	0.3	0.2	0.3	0.1

June 21-22								
	09	79	49A	59A	59B	49B	10	
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7	B *
Tot CO_2	313	288	305	313	355	438	300	293	308
Cl	1	1	1	1	1	2	1	1	2
SO_4	3	4	2	4	3	4	3	3	3
Si	0.8	1.1	0.3	0.8	0.8	0.5	0.7	0.7	0.7
Na	3.0	2.3	1.2	1.1	0.9	2.4	2.2	2.1	2.1
K	1.0	0.7	0.6	0.3	0.4	1.0	0.9	0.9	0.9
Mg	3.0	2.7	2.8	2.8	2.9	3.4	3.1	3.0	3.1
Ca	6.8	7.9	9.1	9.3	10.0	7.8	7.0	6.8	7.5
Mn	0.02	0.03	0.04	0.05	0.03	0.01	0.01	0.01	0.02
Fe	0.08	0.07	0.03	0.08	0.04	-	0.04	0.02	0.06

* B indicates bottom.

June 21-22 (cont.)

	20					30		
	0.5	3	5	7	B	0.5	7	B
Tot CO_2	300	-	300	316	331	308	316	300
Cl	2	1	1	1	1	2	2	2
SO_4	3	3	3	3	3	3	3	3
Si	0.5	0.5	0.6	0.6	0.6	0.4	0.4	0.4
Na	2.2	2.2	2.3	2.3	2.3	2.5	2.6	2.6
K	0.9	0.9	0.9	0.9	0.9	0.9	1.0	0.9
Mg	3.2	3.2	3.2	3.2	3.2	3.4	3.4	3.4
Ca	7.4	7.5	7.4	7.4	7.4	8.1	7.9	7.8
Mn	0.02	0.02	0.03	0.02	0.03	0.04	0.04	0.4
Fe	-	0.06	0.03	0.01	0.05	0.03	0.02	0.03

June 21-22 (cont.)

	40		50			60				
	0.5	7	0.5	7	B	0.5	3	5	7	10
Tot CO_2	.339	362	354	362	354	655	678	608	655	-
Cl	1	2	2	1	1	1	1	1	1	2
SO_4	4	3	3	3	3	3	3	3	3	3
Si	0.3	0.4	0.4	0.4	0.4	1.3	1.3	1.3	1.3	-
Na	2.7	2.7	1.7	1.7	1.7	2.1	2,1	2.1	2.1	2.1
K	1.0	1.0	0.6	0.6	0.6	0.8	0.8	0.8	0.8	0.9
Mg	3.8	3.7	3.5	3.5	3.6	5.2	5.3	5.4	5,3	4.0
Ca	8.8	8.8	10.5	10.7	10.2	18.9	1.86	18.6	18.8	-
Mn	0.04	0.05	0.05	0.05	0.04	0.05	0.05	0.06	0.06	0.06
Fe	0.02	0.05	0.05	0.04	0.03	0.08	0.05	0.05	0.05	-

July 10-11

	09	79	49A	59A	59B	49B	10		
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7	B
Tot CO_2	704	632	812	307	948	912	637	653	729
Cl	1	1	1	1	1	1	1	1	1
SO_4	4	4	4	4	4	3	4	4	4
Si	1.0	1.0	0.3	0.6	0.5	0.3	0.9	0.9	-
Na	2.6	1.2	1.3	1.1	0.9	2.3	2.1	2.1	2.2
K	1.3	0.8	0.7	0.4	0.4	1.1	1.1	1.1	1.0
Mg	3.1	3.0	3.3	3.0	3.4	3.9	2.7	2.8	2.9
Ca	7.6	8.8	10.7	10.7	12.1	9.6	7.2	7.1	7.7
Mn	0.01	0.01	0.01	0.02	0.01	0.01	0.03	0.03	0.03
Fe	0.07	0.10	0.06	0.19	0.07	0.03	0.15	0.15	0.09

July 10-11(cont.)

	20						30		
	0.5	3	5	7	10	B	0.5	7	B
Tot CO_2	628	670	628	645	645	653	704	670	670
Cl	1	1	1	1	1	1	1	1	1
SO_4	4	3	4	4	4	5	4	4	3
Si	0.8	0.8	0.8	0.8	0.8	0.8	0.6	0.7	0.7
Na	2.2	2.2	2.1	2.2	2.2	2.1	2.3	2.3	2.2
K	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mg	2.8	2.9	2.7	2.9	2.9	2.8	3.1	3.2	3.3
Ca	7.4	7.6	7.0	7.7	7.5	7.8	8.7	8.0	8.0
Mn	0.03	0.01	0.05	0.04	0.02	0.03	0.03	0.03	0.04
Fe	0.12	0.12	0.12	0.19	0.10	0.10	0.11	0.11	0.07

July 10-11 (cont.)

	40			50			60				
	0.5	7	B	0.5	5	B	0.5	3	5	7	B
Tot CO_2	745	737	829	796	779	829	1374	1365	1424	1390	1491
Cl	1	1	1	1	1	1	1	1	1	1	1
SO_4	4	4	4	4	3	3	4	4	4	4	4
Si	0.5	0.5	0.3	0.4	0.4	0.4	2.4	2.3	2.3	2.3	2.4
Na	2.4	2.5	2.6	1.6	1.6	1.6	2.0	2.0	1.9	1.9	1.9
K	1.0	1.1	1.1	0.7	0.7	0.7	0.9	0.9	0.9	0.9	0.9
Mg	3.1	3.2	3.3	3.1	2.0	3.1	4.5	4.4	4.5	4.4	4.4
Ca	9.2	11.0	12.0	14.1	12.1	8.3	20.1	20.7	20.8	20.6	21.8
Mn	0.03	0.03	0.03	0.04	0.03	0.03	0.05	0.04	0.03	0.02	0.03
Fe	0.09	0.09	0.07	0.09	0.13	0.07	0.13	0.10	0.13	0.09	0.13

August 1

	09	79	49A	59A	59B	49B	10		
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7	B
Tot CO_2	460	350	440	460	420	420	420	480	420
Cl	1	< 1	1	< 1	< 1	1	1	1	1
SO_4	4	4	4	4	3	4	4	4	4
Si	0.7	0.9	0.2	0.6	0.7	0.4	0.9	0.9	0.9
Na	2.6	1.1	1.2	1.0	0.8	2.3	2.2	2.2	2.2
K	1.2	0.7	0.6	0.4	0.3	1.0	1.2	1.1	1.1
Mg	3.6	3.1	3.7	3.4	3.7	3.8	3.4	3.3	3.2
Ca	8.0	8.7	11.9	11.6	12.8	9.0	7.6	8.1	8.6
Mn	-	0.02	-	-	-	-	0.01	0.01	0.01
Fe	0.07	0.10	0.05	0.10	0.06	0.01	0.06	0.07	0.06

August 1 (cont.)

	20						30			40	
	0.5	3	5	7	10	B	0.5	7	B	0.5	7
Tot CO_2	310	350	330	390	450	400	420	350	350	320	350
Cl	1	1	1	1	1	1	1	2	1	1	1
SO_4	4	4	4	4	3	4	4	2	4	5	4
Si	0.9	0.9	0.9	0.9	0.9	-	0.8	0.8	0.8	0.3	0.3
Na	2.1	2.1	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.4	2.4
K	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Mg	3.2	3.2	3.4	3.2	3.2	3.2	3.3	3.3	3.3	3.7	3.7
Ca	7.3	7.2	7.2	7.4	7.4	7.3	7.9	7.5	7.6	8.8	8.8
Mn	-	-	-	-	-	0.01	0.01	-	-	0.01	-
Fe	0.05	0.05	0.06	0.06	0.05	0.03	0.06	-	0.03	0.06	0.03

August 1 (cont.)

	50			60					70
	0.5	5	B	0.5	3	5	7	B	0.5
Tot CO_2	500	390	490	760	640	770	780	620	300
Cl	1	1	1	1	1	1	1	-	1
SO_4	4	3	4	4	4	4	4	4	4
Si	0.4	0.4	0.5	-	1.5	1.5	1.6	1.6	0.9
Na	1.7	1.7	1.6	1.9	1.9	2.0	1.9	1.9	2.1
K	0.7	0.7	0.7	0.9	0.9	0.9	0.9	0.9	1.0
Mg	3.5	3.5	3.4	5.2	5.2	5.4	5.3	5.8	3.2
Ca	10.4	10.6	10.6	21.4	21.2	21.8	21.6	21.2	7.6
Mn	-	-	-	0.01	0.01	-	0.01	-	-
Fe	0.01	0.03	0.03	0.05	0.02	0.06	0.04	0.03	0.10

August 21

	09	79	49A	59A	59B	49B	10			20					
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7	B	0.5	3	5	7	10	B
Tot CO_2	510	410	580	530	600	400	470	530	510	-	450	480	430	460	460
Cl	1	1	1	1	1	1	1	1	-	<1	1	1	1	1	1
SO_4	5	4	4	4	3	4	4	4	5	6	4	4	4	4	4
Si	0.8	0.8	0.3	0.7	0.8	0.5	0.9	0.9	-	0.9	0.9	0.9	0.9	0.9	1.0
Na	2.8	1.2	1.2	1.0	0.8	2.3	2.6	2.6	2.6	2.3	2.3	2.3	2.3	2.4	2.3
K	1.2	0.6	0.5	0.3	0.3	1.0	1.2	1.1	1.2	1.1	1.1	1.1	1.1	1.1	1.1
Mg	4.2	3.1	3.6	3.5	3.7	3.4	3.5	3.4	3.3	3.1	3.2	3.1	3.2	3.1	3.2
Ca	10.1	10.2	12.2	12.9	15.7	8.9	9.3	8.5	8.3	8.4	8.0	8.4	7.7	7.5	8.1
Mn	0.03	0.04	0.02	0.07	0.03	0.05	0.04	0.05	0.04	0.03	0.03	0.03	0.03	0.04	0.05
Fe	0.13	0.23	0.13	0.22	0.13	0.05	0.08	0.06	0.14	0.07	0.14	0.09	0.09	0.08	0.17

August 21 (cont.)

	30			40			50			60			
	0.5	7	B	0.5	7	B	0.5	3	B	0.5	3	5	B
Tot CO_2	460	500	460	490	500	460	520	540	560	970	960	960	970
Cl	< 1	1	1	1	1	1	< 1	1	1	1	1	1	1
SO_4	4	4	4	4	4	4	4	4	4	4	4	4	4
Si	1.0	0.9	1.2	0.6	0.6	0.9	0.6	0.6	0.6	1.5	1.3	1.5	1.5
Na	2.2	2.2	-	2.5	2.3	2.4	1.6	1.6	1.6	1.9	1.9	1.9	2.0
K	1.1	1.0	1.0	1.2	1.1	1.1	0.7	0.7	0.7	0.9	0.9	0.9	0.9
Mg	3.0	3.0	3.2	3.4	3.7	3.7	3.6	3.6	3.5	5.4	5.3	5.5	5.4
Ca	8.9	8.5	7.9	7.8	9.4	8.6	10.6	10.5	10.1	21.6	21.7	22.7	21.8
Mn	0.06	0.04	0.04	0.03	0.04	0.02	0.04	0.05	0.03	0.03	0.04	0.04	0.04
Fe	0.04	0.13	0.11	0.08	0.07	0.07	0.07	0.08	0.10	0.09	0.11	0.07	0.07

September 12

		09	79	49A	59A	59B	49B	10			20					
		0.5	0.5	0.5	0.5	0.5	0.5	0.5	7	B	0.5	3	5	7	10	B
Tot CO_2		918	700	890	1000	1040	780	860	860	860	770	808	720	760	760	770
Cl		1	< 1	1	< 1	1	1	1	1	1	1	1	1	1	1	1
SO_4		5	4	4	4	4	4	5	5	4	4	4	4	4	4	4
Si		1.3	0.9	0.4	0.8	1.0	0.5	1.1	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8
Na		2.8	1.1	1.3	1.1	0.8	2.2	2.7	2.7	2.7	2.5	2.4	2.5	2.5	2.5	2.5
K		1.2	0.6	0.6	0.3	0.3	0.9	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Mg		4.2	3.1	3.8	4.0	4.0	3.5	4.0	4.0	4.0	3.6	3.6	3.5	3.6	3.6	3.5
Ca		9.7	9.3	11.7	18.9	14.7	9.1	9.2	9.3	9.0	8.5	8.5	8.4	8.5	8.4	8.5
Fe		0.10	0.12	0.17	0.19	0.13	0.09	0.08	0.06	0.13	0.10	0.15	0.11	0.15	0.11	0.12
Zn	mg/1	-	-	-	-	-	-	0.004	-	-	0.06	-	-	-	-	-
Cd	mg/1	-	-	-	-	-	-	0.002	-	-	0.03	-	-	-	-	-
Pb	mg/1	-	-	-	-	-	-	0.002	-	-	0.05	-	-	-	-	-

September 12 (cont.)

	30			40			50			60				
	0.5	7	B	0.5	7	B	0.5	7	B	0.5	3	5	7	B
Tot CO_2	710	760	760	775	770	780	890	880	620	1600	1500	1550	1460	1500
Cl	1	1	1	1	2	1	< 1	1	1	1	1	1	1	1
SO_4	4	4	4	4	5	5	4	4	-	4	4	8	7	4
Si	0.7	0.7	0.7	0.5	0.5	0.5	0.6	0.6	0.6	1.5	1.5	1.5	1.5	1.5
Na	2.2	2.2	2.2	2.3	2.2	2.3	1.6	1.6	1.6	2.0	2.0	-	-	1.9
K	1.0	1.0	1.0	1.0	1.0	0.9	0.7	0.7	0.7	1.0	0.9	0.9	0.9	0.9
Mg	3.3	3.2	3.3	3.9	3.5	3.5	3.6	3.6	3.5	5.5	5.6	5.6	5.6	5.6
Ca	8.0	7.9	8.0	10.3	8.7	9.6	10.6	10.9	10.1	20.7	20.9	20.0	20.3	22.0
Fe	0.10	0.13	0.11	0.09	0.08	0.10	0.09	0.06	0.10	0.12	0.13	0.14	0.10	0.10
Zn	-	-	-	0.012	-	-	0.003	-	-	0.002	-	-	-	-
Cd	-	-	-	0.001	-	-	0.001			0.001				

- - - 0.001 - - 0.002 - - 0.002 - - - -

Oɵtober 3-4

	09 0.5	49B 0.5	10 0.5	20 0.5	B	30 0.5	40 0.5	50 0.5	60 0.5	B
Tot CO_2	860	690	840	810	790	740	780	820	1420	1390
Cl	1	1	1	1	1	1	1	1	1	1
SO_4	5	4	4	4	4	4	4	4	4	4
Si	1.3	0.3	1.2	1.0	0.9	0.6	-	0.5	1.3	1.3
Na	3.0	2.2	2.8	2.6	2.6	2.5	2.4	1.6	1.9	2.2
K	1.3	1.0	1.2	1.1	1.1	1.1	1.0	0.7	0.9	0.9
Mg	4.3	3.5	4.1	3.8	3.8	3.5	3.5	3.5	5.5	5.6
Ca	9.6	8.5	9.3	8.9	8.9	8.6	8.5	10.5	20.2	20.2
Mn	0.01	0.02	0.01	0.01	-	-	-	-	-	-
Fe	0.09	0.10	0.10	0.10	0.10	0.11	0.11	0.13	0.13	0.13

December 10

	59B 0.5	10 0.5	B	20 0.5	B	40 0.5	B	50 0.5	B	60 0.5
Tot CO_2	440	250	260	270	270	280	250	280	270	460
Cl	1	1	1	1	1	< 1	1	1	1	1
SO_4	4	5	4	4	4	5	4	4	4	5
Si	1.6	1.6	1.7	1.7	1.8	1.3	1.2	0.5	0.5	1.6
Na	1.4	3.3	3.3	3.3	3.3	3.1	3.0	2.1	2.0	2.5
K	0.6	1.3	1.3	1.3	1.3	1.3	1.2	0.8	0.8	1.1
Mg	5.6	4.4	4.4	4.4	4.4	4.2	4.0	4.2	3.9	6.1

	February 28		March 28										
	09	49B	09	49B	10	20		40		50	60		
	0.5	0.5	0.5	0.5	0.5	0.5	B	0.5	B	0.5	0.5	4	B
CO_2	990	1080	-	-	714	890	310	550	780	850	1216	1307	1452
Cl	1.5	1.4	1	1	1	1	1	1	1	1	1	1	1
SO_4	4.8	5.2	4	5	4	5	5	5	4	5	4	4	4
Si	1.4	1.5	1.6	1.5	1.3	1.6	1.5	1.5	2.1	0.4	1.7	1.3	1.3
Na	3.4	3.2	2.6	3.3	2.8	2.8	3.0	3.0	2.5	2.5	2.5	2.4	2.3
K	1.6	1.4	1.0	1.4	1.3	1.2	1.2	1.3	1.0	1.0	1.3	1.2	1.1
Mg	3.9	4.4	3.6	4.6	3.6	4.2	4.3	4.5	4.1	4.6	7.2	6.9	7.0
Ca	9.4	10.7	9.1	11.1	15.4	10.0	10.2	10.8	10.6	12.4	25.3	23.7	24.3
Mn	-	0.02	0.01	-	0.03	0.01	0.01	0.01	0.02	-	0.04	0.03	0.02
Fe	0.03	0.02	0.05	0.19	0.04	0.08	0.45	0.24	0.18	0.11	0.31	0.08	0.07

Southern Indian Lake

	June 1						June 21-22					
	09	79	49A	59A	59B	49B	09	79	49A	59A	59B	49B
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
NO_3-N μg/l	18	2	5	23	6	13	17	8	10	5	7	5
TDN μg/l	300	480	380	550	380	400	360	450	400	430	410	400
Susp Nμg/l	60	50	100	100	90	90	70	80	110	80	70	100
TDP μg/l	9	15	10	13	11	10	14	15	16	17	19	15
Susp Pμg/l	13	14	15	22	10	12	10	14	18	11	8	10
Chl a μg/l	3.2	4.7	3.9	4.1	3.3	3.9	1.4	2.2	2.1	2.0	0.4	2.5
Cond μ mhos/l	68	58	54	66	79	94	67	61	67	65	70	79
pH	-	-	-	-	-	-	7.8	7.7	7.7	7.7	7.7	7.8
TDS mg/l	30	50	30	60	60	70	50	50	50	50	50	50
TSS mg/l	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C μg/l	730	660	910	800	740	690	540	720	960	690	450	1030

June 21-22 (cont.)

	10			20					30			40		50		
	0.5	7	B	0.5	3	5	7	B	0.5	7	B	0.5	7	0.5	7	B
NO_3-N	5	4	3	4	3	3	5	3	-	2	2	3	3	3	3	4
TDN	340	310	290	270	290	290	-	-	-	-	330	310	-	330	310	310
Susp N	60	50	50	40	50	50	60	60	50	70	40	50	80	50	60	60
TDP	11	10	12	13	9	8	-	8	20	15	7	-	8	11	14	8
Susp P	8	9	11	6	8	7	8	8	8	9	8	7	9	7	6	6
Chl a	3.1	3.0	2.5	1.9	2.9	2.3	1.0	-	-	1.4	1.6	1.0	1.6	1.0	1.2	1.2
Cond	69	68	71	72	72	72	71	71	77	76	76	81	83	81	82	82
pH	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.7	7.8	7.8	7.8	7.8	7.8	7.6	7.8	7.8
TDS	60	60	60	60	50	50	60	70	50	60	60	30	50	60	60	70
TSS	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	500	540	610	410	450	620	540	530	440	610	480	570	720	690	740	670

June 21-22 (cont.)						July 10, 11					
	60					09	79	49A	59A	59B	49B
	0.5	3	5	7	10	0.5	0.5	0.5	0.5	0.5	0.5
NO_3-N	5	9	6	4	-	20	9	11	21	29	33
TDN	320	300	290	-	-	410	440	450	-	-	360
Susp N	50	50	60	50	-	150	110	190	60	60	50
TDP	12	12	9	12	-	22	17	14	17	14	16
Susp P	4	7	7	7	-	11	18	22	12	14	8
Chl a	0.8	0.6	0.3	0.5	-	3.9	6.0	7.1	4.1	3.8	3.7
Cond	131	131	131	132	-	68	63	78	70	80	84
pH	8.0	8.0	8.0	8.0	8.0	7.8	7.9	7.9	7.8	7.9	8.0
TDS	90	80	-	100	90	50	50	50	60	50	50
TSS	<10	<10	<10	<10	-	<10	<10	<10	<10	<10	<10
Susp C	470	350	400	370	-	920	1020	1430	420	540	510

July 10, 11 (cont.)

	10			20						30			40		
	0.5	7	B	0.5	3	5	7	10	B	0.5	7	B	0.5	7	B
NO_3-N	17	41	22	32	18	13	21	25	25	17	15	23	15	28	26
TDN	250	300	230	240	240	250	240	240	-	250	230	250	220	230	300
Susp N	70	90	110	90	90	100	80	80	80	60	70	40	80	50	50
TDP	12	14	61	10	9	9	9	9	-	10	14	16	12	12	16
Susp P	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chl a	1.8	4.6	1.9	4.3	5.1	4.3	4.8	3.7	3.2	1.8	3.4	0.5	1.4	1.6	1.5
Cond	75	75	71	69	69	69	68	69	69	73	73	74	77	77	82
pH	8.0	7.8	7.6	7.8	7.7	7.7	7.7	7.8	7.8	7.9	7.8	7.5	7.9	8.0	7.9
TDS	50	60	60	60	60	60	80	50	60	60	60	60	110	110	110
TSS	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	340	710	560	900	670	1070	630	590	600	590	630	430	980	-	660

July 10, 11 (cont.)

	50			50					August 1					
									09	79	49A	59A	59B	49B
	0.5	5	B	0.5	3	5	7	B	0.5	0.5	0.5	0.5	0.5	0.5
NO_3-N	21	17	26	26	35	17	19	31	16	5	7	7	10	9
TDN	270	250	340	310	350	-	-	300	360	390	370	380	-	260
Susp N	40	40	-	50	40	30	40	40	130	90	180	80	80	70
TDP	16	12	14	16	17	16	16	16	8	9	6	8	6	5
Susp P	-	-	-	-	-	-	-	-	20	12	17	8	8	7
Chl a	2.2	1.5	1.2	1.7	0.4	0.7	1.9	1.1	4.6	3.3	4.5	2.6	1.3	1.2
Cond	83	83	83	133	133	132	134	135	75	64	84	77	83	81
pH	8.0	8.0	7.9	8.1	8.2	8.2	8.2	8.0	7.8	7.8	8.1	7.8	7.9	8.0
TDS	50	50	50	40	90	70	90	100	50	60	100	30	90	50
TSS	<10	<10	-	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	1050	780	-	540	520	-	480	430	920	860	1460	800	900	500

August 1 (cont.)

	10			20						30			40	
	0.5	7	B	0.5	3	5	7	10	B	0.5	7	B	0.5	7
NO_3-N	9	9	11	10	9	11	8	7	8	9	7	6	9	8
TDN	230	320	310	290	270	290	270	290	-	380	310	280	270	280
Susp N	130	120	140	100	70	90	100	100	-	100	110	-	30	60
TDP	7	9	7	7	7	7	7	8	7	5	7	8	8	6
Susp P	15	16	17	10	13	13	15	11	-	12	11	10	9	8
Chl a	2.5	1.9	2.3	5.0	4.2	2.3	3.9	1.1	-	4.5	2.9	1.8	2.7	2.9
Cond	70	70	69	68	68	68	68	67	68	71	71	71	80	81
pH	7.8	7.9	7.8	7.9	7.8	7.8	8.2	8.1	7.9	7.8	7.9	7.9	7.8	7.9
TDS	30	90	80	40	90	60	40	80	80	80	100	90	100	110
TSS	<10	<10	<10	<10	<10	<10	<10	<10	-	<10	<10	<10	<10	<10
Susp C	770	840	720	590	390	680	680	650	-	820	730	830	540	540

										August 21					
	50			60					70	09	79	49A	59A	59B	49B
	0.5	5	B	0.5	3	5	7	B	0.5	0.5	0.5	0.5	0.5	0.5	0.5
NO_3-N	8	5	7	5	7	7	7	4	5	7	5	5	13	6	8
TDN	330	-	260	250	-	280	-	260	-	220	230	-	-	400	180
Susp N	50	80	110	60	70	50	60	40	70	260	190	240	210	220	210
TDP	10	6	6	8	8	8	8	7	12	8	8	6	8	6	6
Susp P	9	9	12	8	6	7	8	8	12	13	11	18	9	7	9
Chl a	1.9	-	1.7	3.3	2.6	2.1	2.7	1.2	-	11.1	4.6	5.6	4.4	2.7	2.8
Cond	82	78	82	133	132	132	134	131	68	81	60	87	81	87	77
pH	7.9	7.8	7.8	8.1	8.2	8.2	8.2	8.2	8.1	-	-	-	-	-	-
TDS	70	80	90	120	120	120	120	100	80	60	30	70	30	70	40
TSS	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	420	730	810	620	520	420	440	410	540	710	670	890	720	640	640

August 21 (cont.)

	10			20						30			40		
	0.5	7	B	0.5	3	5	7	10	B	0.5	7	B	0.5	7	B
NO_3-N	9	6	10	7	6	6	7	7	8	10	8	18	8	8	10
TDN	270	210	-	230	210	280	280	280	340	220	260	220	230	200	250
Susp N	130	70	70	100	80	80	90	70	90	90	80	70	100	80	60
TDP	6	8	9	9	6	6	7	7	11	8	8	7	7	7	8
Susp P	11	12	16	10	9	10	11	10	16	11	11	16	10	12	13
Chl a	5.4	-	5.7	7.1	7.5	7.8	4.0	6.0	3.9	2.0	6.9	1.7	4.5	6.1	3.2
Cond	78	70	77	65	72	72	72	72	72	80	67	71	77	85	78
pH	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
TDS	70	50	60	30	60	60	50	40	50	30	50	40	30	50	40
TSS	<10	<10	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	720	700	790	770	780	720	760	820	940	810	1060	710	750	720	580

								September 12					
	50			60				09	79	49A	59A	59B	49B
	0.5	5	B	0.5	3	5	B	0.5	0.5	0.5	0.5	0.5	0.5
NO_3-N	8	7	8	8	8	8	10	5	7	7	< 1	< 1	5
TDN	200	180	190	200	180	260	210	310	330	320	350	350	270
Susp N	60	50	60	40	40	30	50	80	70	120	90	70	70
TDP	5	4	5	7	8	7	10	8	19	9	22	7	8
Susp P	6	8	8	7	7	6	16	12	13	17	17	7	12
Chl a	4.3	4.4	3.6	3.3	3.2	4.1	1.5	3.4	5.0	8.2	5.6	4.8	7.4
Cond	82	82	82	136	136	136	136	86	70	68	91	92	79
pH	-	-	-	-	-	-	-	7.9	8.0	8.0	8.3	8.0	7.9
TDS	70	40	40	80	60	100	70	60	-	60	90	70	60
TSS	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	670	630	670	550	550	400	490	730	680	1140	920	740	730

September 12 (cont.)

	10			20						30			40		
	0.5	7	B	0.5	3	5	7	10	B	0.5	7	B	0.5	7	B
NO_3-N	9	19	7	5	5	7	10	9	7	<1	7	5	8	< 1	< 1
TDN	280	350	320	300	280	260	330	280	300	250	230	230	-	210	230
Susp N	50	110	80	90	70	80	80	80	80	80	120	90	80	70	70
TDP	10	10	10	7	8	7	7	7	7	7	7	7	-	18	13
Susp P	11	15	16	12	12	11	12	16	11	12	12	13	13	10	13
Chl a	5.5	7.0	11.0	3.8	7.3	7.7	8.8	12.9	11.4	8.3	9.0	3.9	8.4	2.2	0.5
Cond	84	85	85	77	78	78	78	78	78	72	73	73	82	77	78
pH	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	7.9	8.0	7.9	7.9	8.1	8.0	8.0
TDS	-	-	-	50	50	60	60	60	60	50	50	50	60	60	60
TSS	<10	<10	10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	750	870	770	690	660	780	600	640	670	830	850	790	720	760	730

									October 3	
	50			60					09	49B
	0.5	7	B	0.5	3	5	7	B	0.5	0.5
NO_3-N	12	5	6	6	7	7	9	5	9	8
TDN	270	280	230	260	260	230	240	260	300	260
Susp N	80	50	70	60	50	50	50	50	70	70
TDP	15	10	11	9	9	8	6	9	18	12
Susp P	10	11	13	9	10	8	8	10	12	7
Chl a	2.1	1.6	5.9	4.5	2.9	3.5	1.9	2.4	-	9.9
Cond	82	82	82	147	148	147	147	146	90	76
pH	8.0	7.9	7.9	8.1	8.1	8.1		8.2	8.0	7.9
TDS	60	70	70	90	100	110	100	100	60	60
TSS	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	670	490	680	580	560	560	510	570	610	660

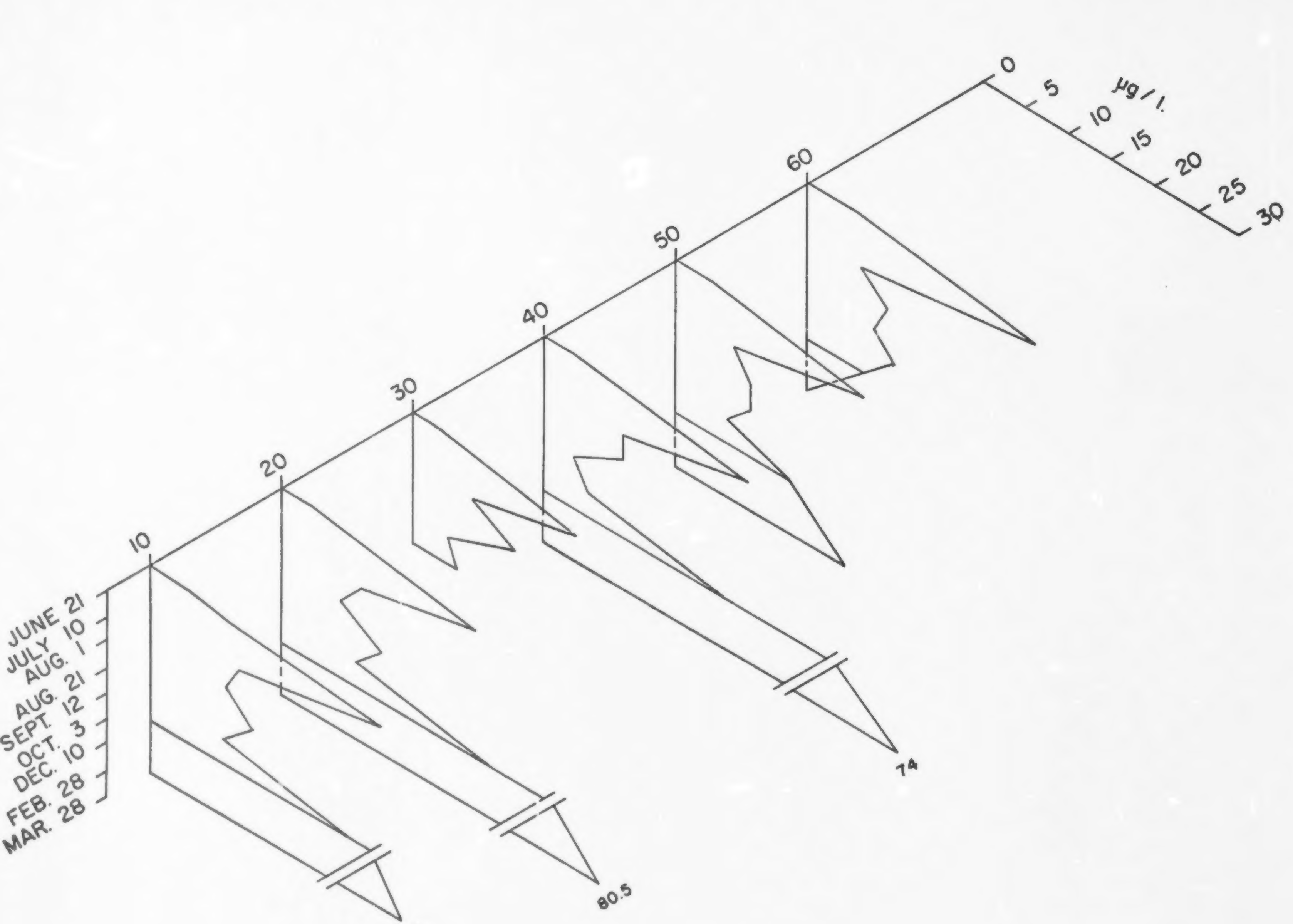
October 3 (cont.)

									December 10						
	10	20		30	40	50	60		59B	10		20		40	
	0.5	0.5	B	0.5	0.5	0.5	0.5	B	0.5	0.5	B	0.5	B	0.5	B
NO_3-N	5	6	9	< 5	< 5	6	9	10	44	21	24	22	24	18	21
TDN	230	300	320	180	260	250	230	200	430	280	280	290	360	270	280
Susp N	80	80	70	60	90	80	40	50	60	-	-	30	-	20	20
TDP	13	15	14	13	11	12	17	17	20	19	20	18	21	21	19
Susp P	7	7	8	7	6	7	7	8	5	7	-	6	-	5	5
Chl a	7.0	4.7	5.1	8.2	2.0	3.8	3.6	4.9	0.7	-	-	-	-	0.5	1.8
Cond	86	83	82	77	76	82	138	138	130	92	91	94	85	91	88
pH	7.8	7.8	7.8	7.8	7.8	7.8	7.9	8.0	7.8	7.8	7.5	7.9	7.7	7.8	7.9
TDS	60	70	60	60	50	60	90	90	120	70	70	100	70	40	80
TSS	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	620	600	580	510	600	580	410	490	940	1200	1400	570	1160	420	620
Turb ppm									1	9	19	9	18.5	6.5	6.5

				February 28		March 28, 1973							
	50		60	09	49B	09	49	10	20		40		50
	0.5	B	0.5	0.5	0.5	0.5	0.5	0.5	0.5	B	0.5	B	0.5
NO_3-N	19	6	7	41	41	85	75	63	77	84	74	-	19
TDN	260	250	240	450	425	323	419	281	363	416	256	392	252
Susp N	20	30	20	36	32	-	61	59	-	-	-	-	16
TDP	19	18	18	25	28	19	35	17	25	21	24	21	35
Susp P	7	4	3	5	3	4	4	8	5	-	4	5	2
Chl a	0.2	0.1	-	0.8	0.5	0.5	0.4	0.6	1.5	0.6	0.6	0.4	1.1
Cond	97	93	157	89	101	75	95	80	85	90	90	90	95
pH	7.7	7.9	8.1	7.9	7.6	7.5	7.8	7.5	7.7	7.6	7.6	-	7.8
TDS	90	60	100	107	125	78	86	24	97	89	91	77	96
TSS	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
Susp C	600	440	560	350	430	548	-	815	610	-	-	710	509
Turb ppm	0	4	19										

March 28, 1973 (cont.)

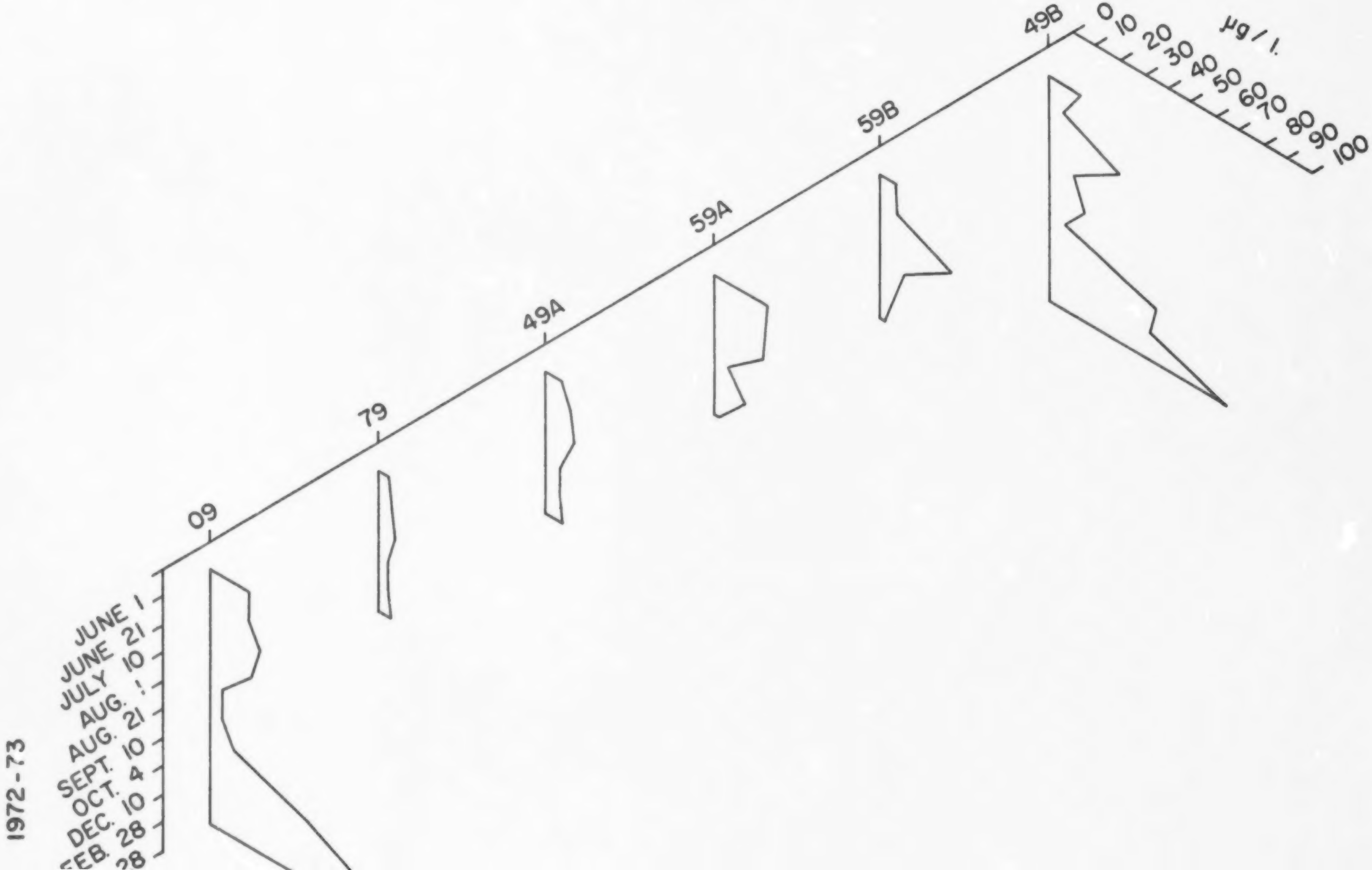
	60		
	0.5	4	B
NO_3-N	< 1	< 1	-
TDN	222	224	236
Susp N	-	-	3
TDP	11	21	19
Susp P	4	1	-
Chl a	1.4	0.2	0.2
Cond	165	160	165
pH	8.0	-	7.9
TDS	63	34	54
TSS	<10	<10	<10
Susp C	330	310	272



0
5
10
15
20
25
30
µg/l.
10
20
30
40
50
60
JUNE 21
JULY 10
AUG. 1
AUG. 21
SEPT. 12
OCT. 3
DEC. 10
FEB. 28
MAR. 28
63
80.5
74

1972-73

Figure 1 . Nitrogen (nitrate), Southern Indian Lake.



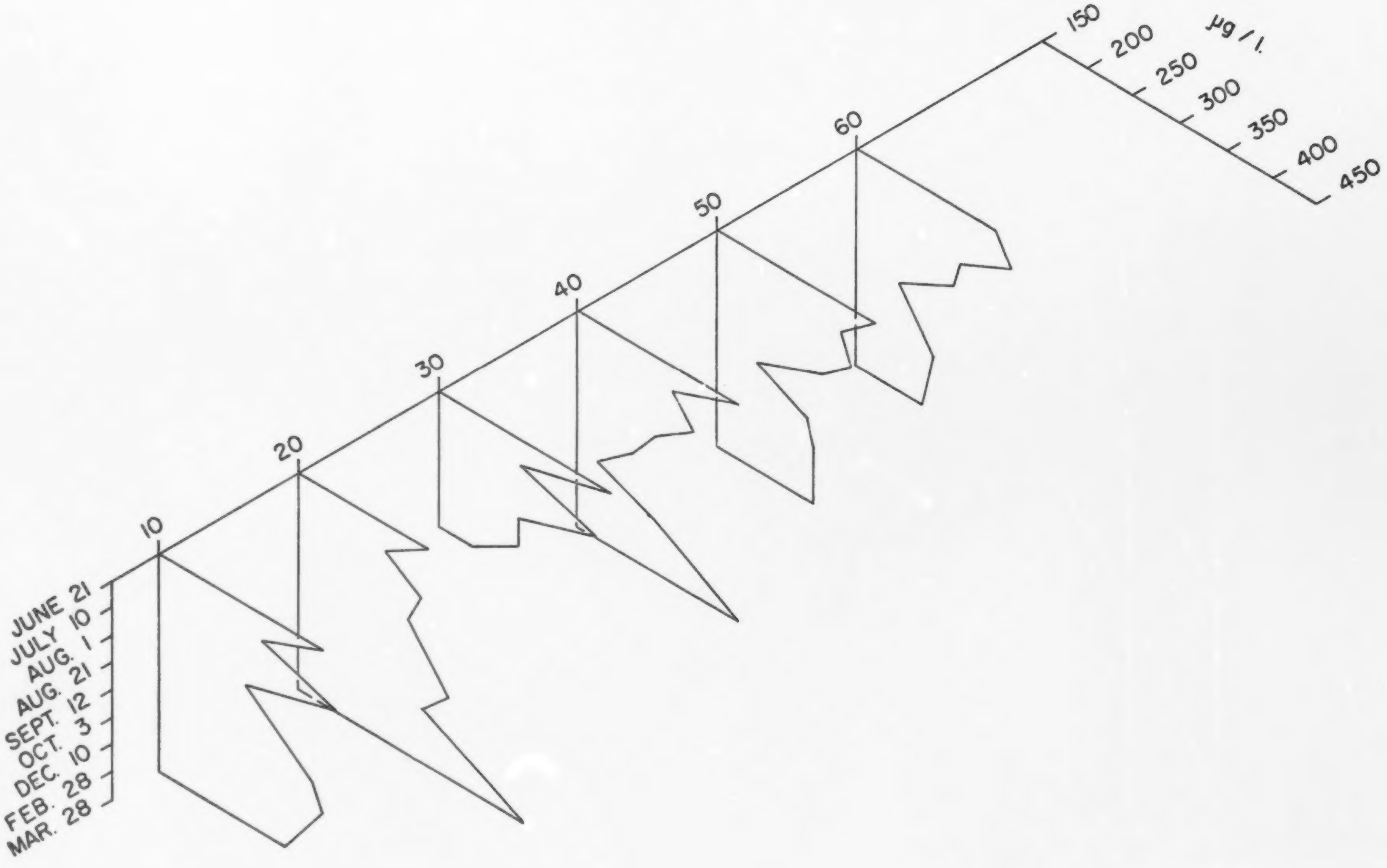


Figure 2 . Nitrogen (nitrate), Southern Indian Lake.

Figure 3 . Total dissolved nitrogen, Southern Indian Lake.

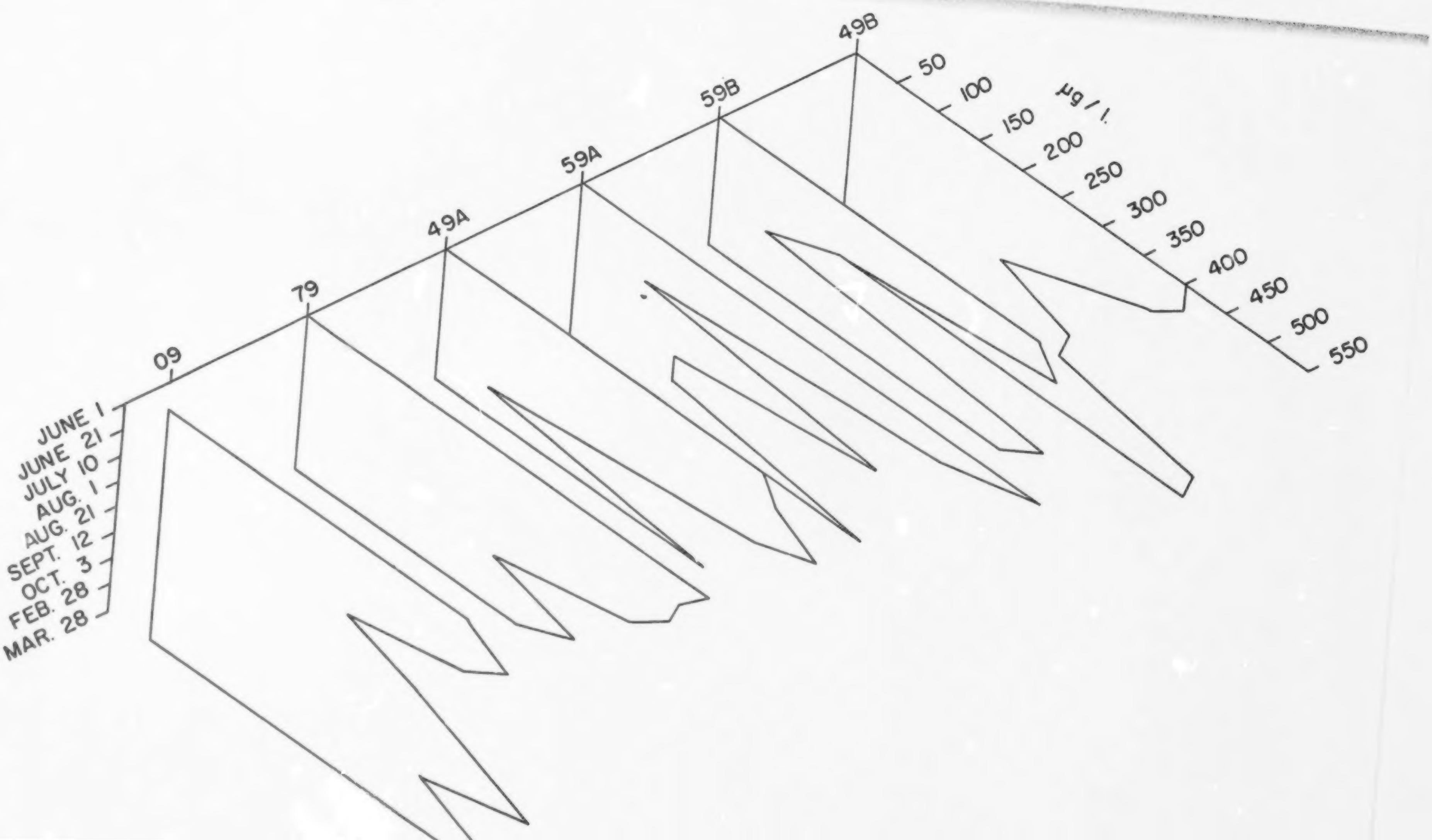


Figure 4 . Total dissolved nitrogen, Southern Indian Lake.

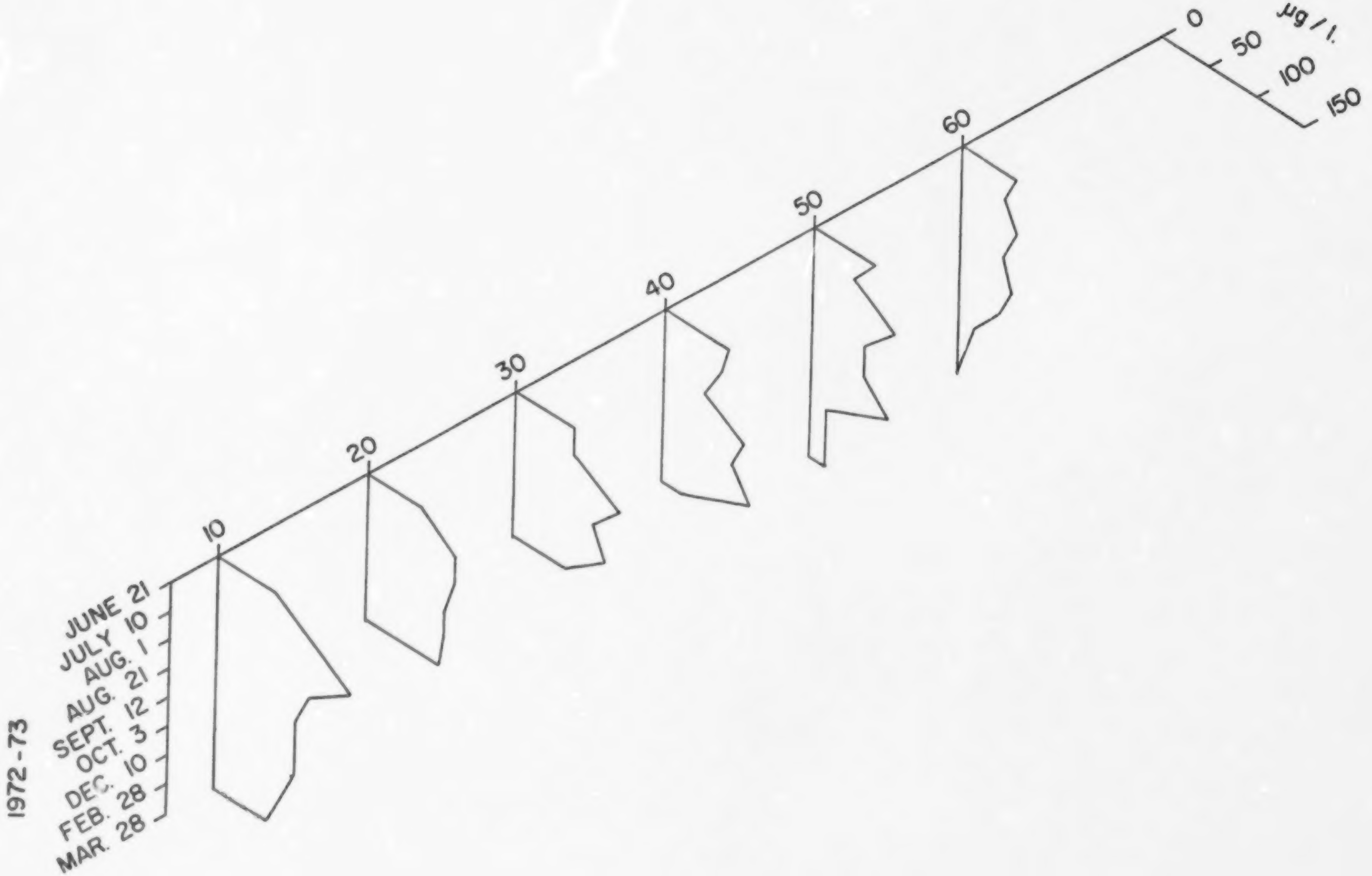
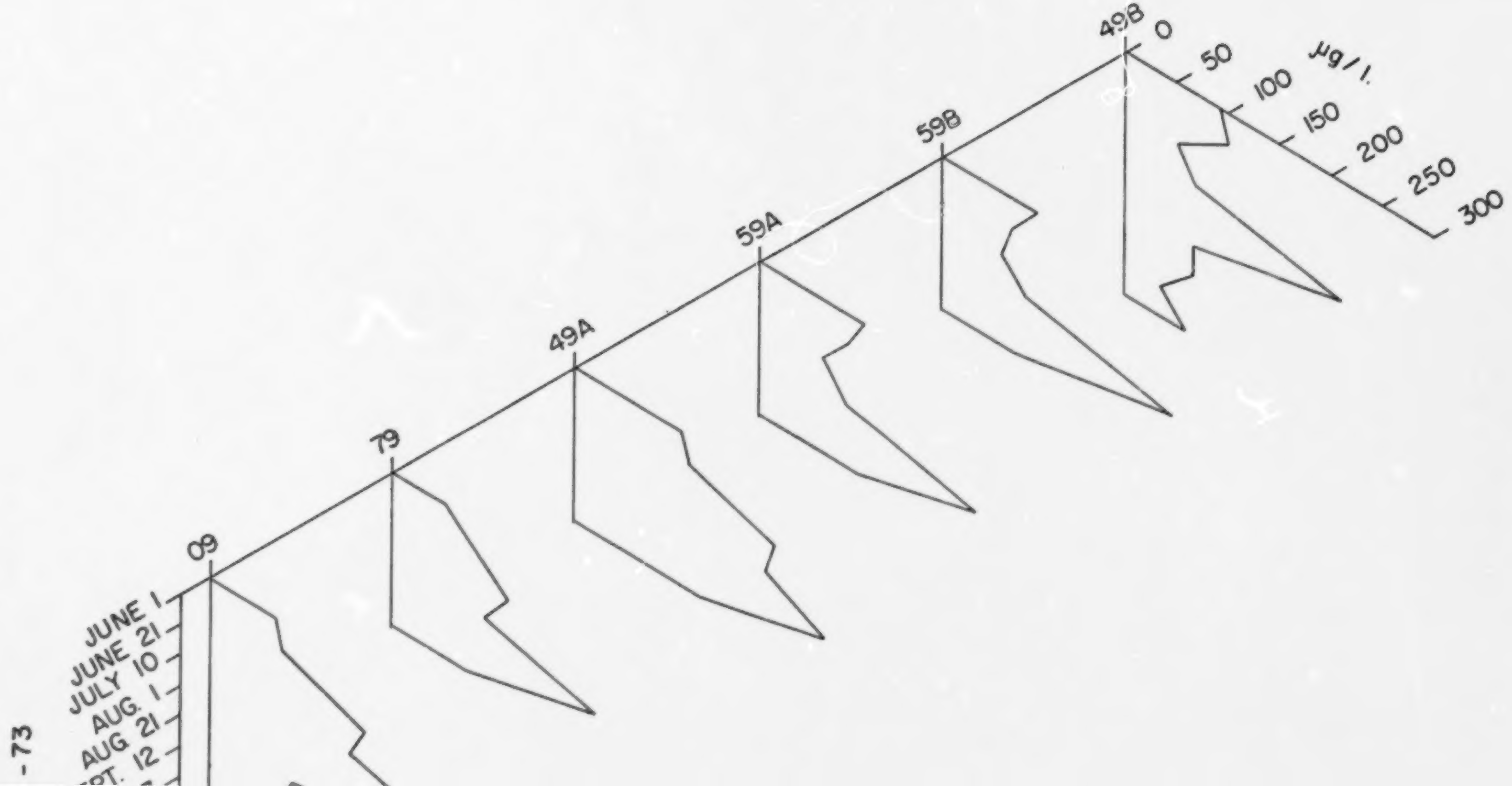


Figure 5 . Suspended nitrogen, Southern Indian Lake.



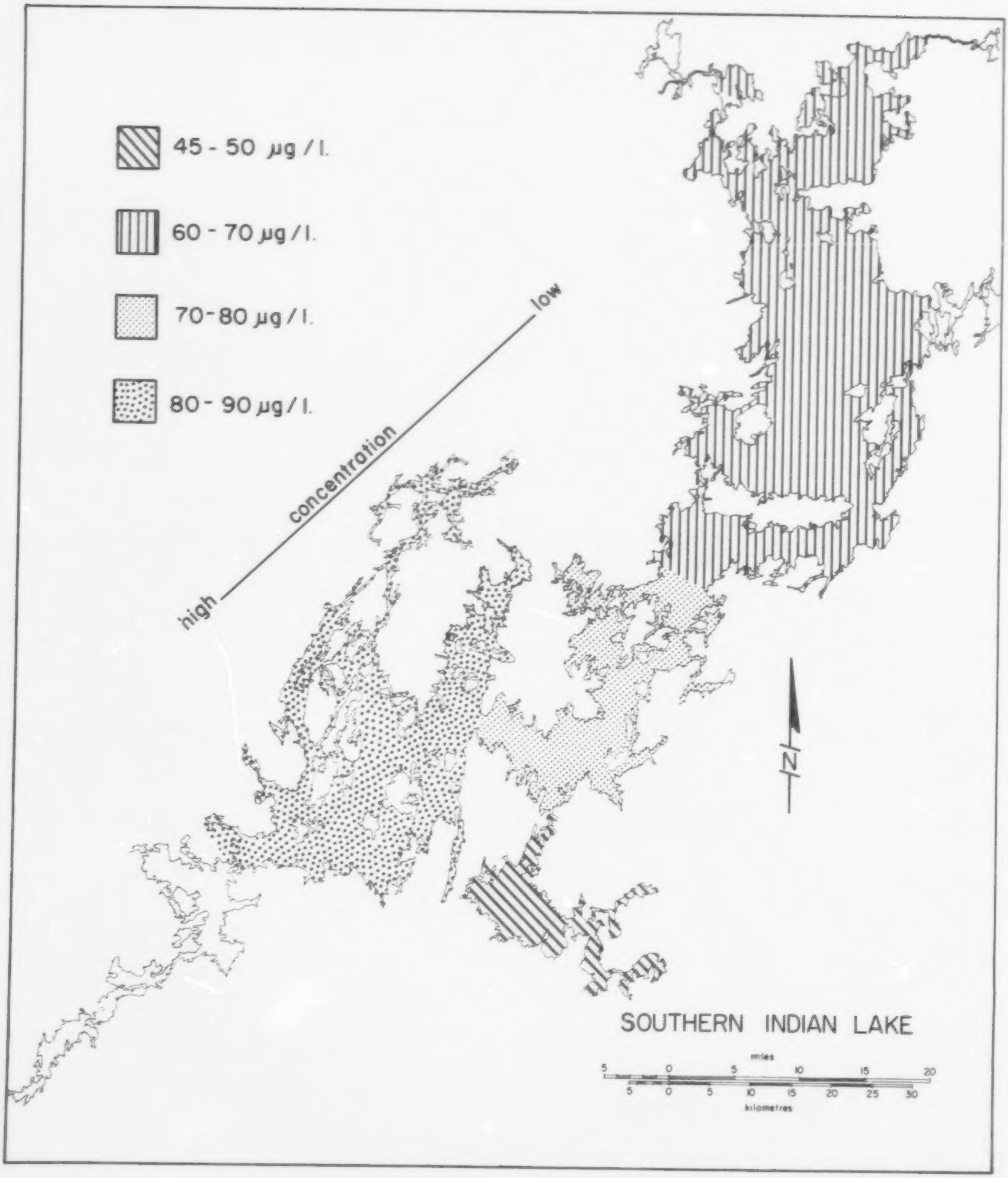

45 - 50 µg / l.
60 - 70 µg / l.
70-80 µg / l.
80 - 90 µg / l.
high
concentration
low
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

Figure 7 . Suspended nitrogen, June-October 1972.

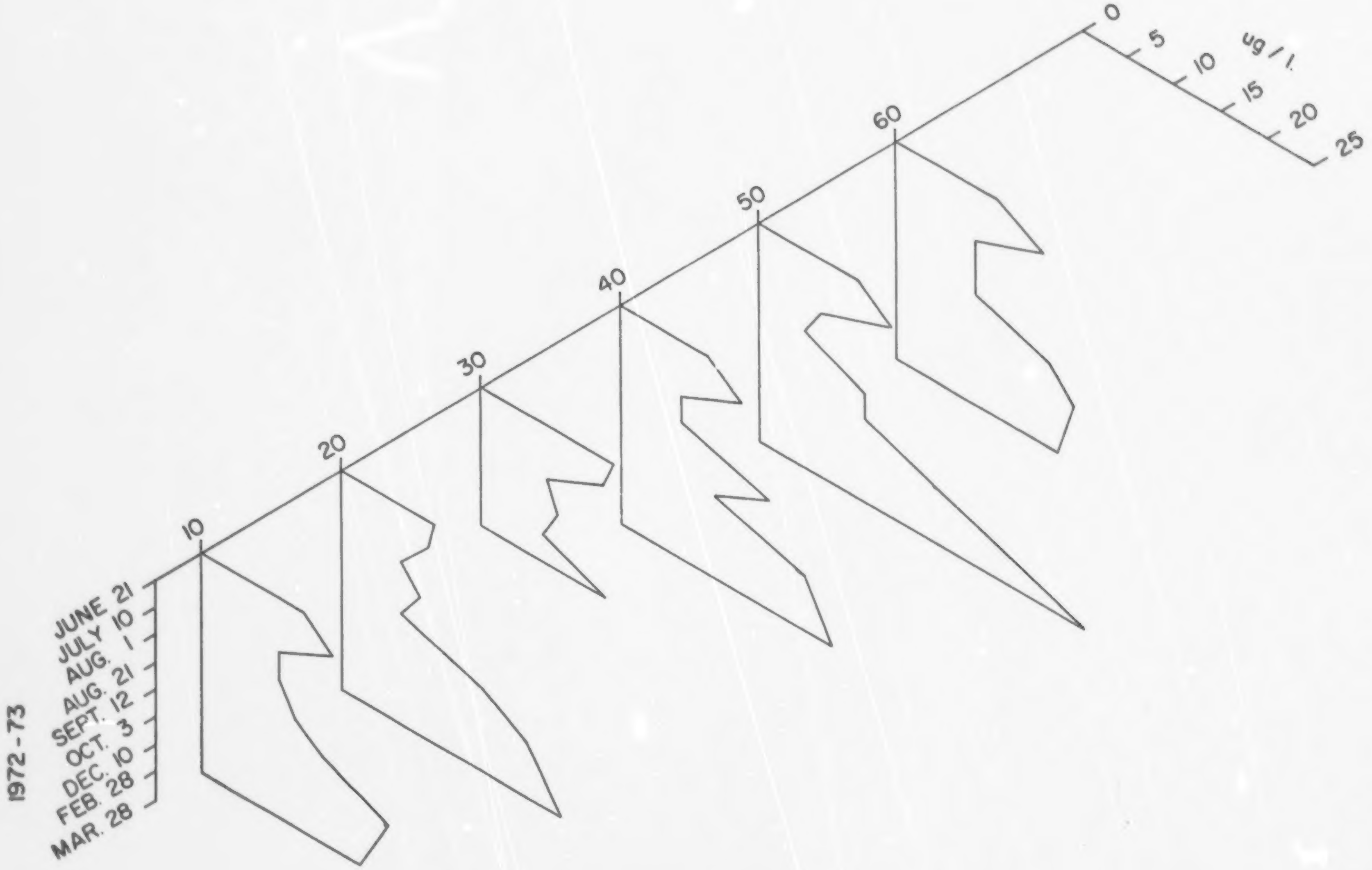


Figure 8 . Total dissolved phosphorus, Southern Indian Lake.

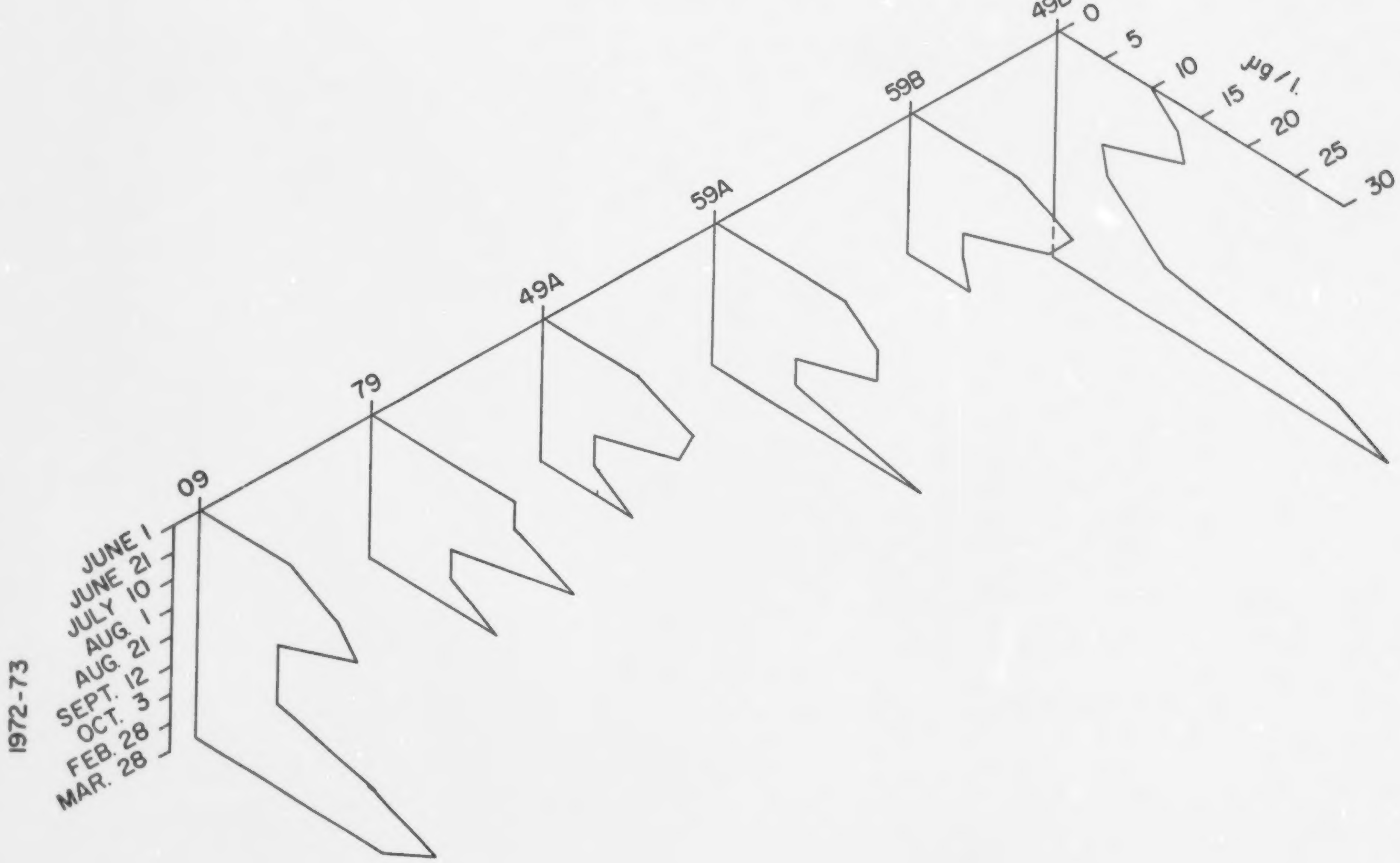


Figure 9 . Total dissolved phosphorus, Southern Indian Lake.

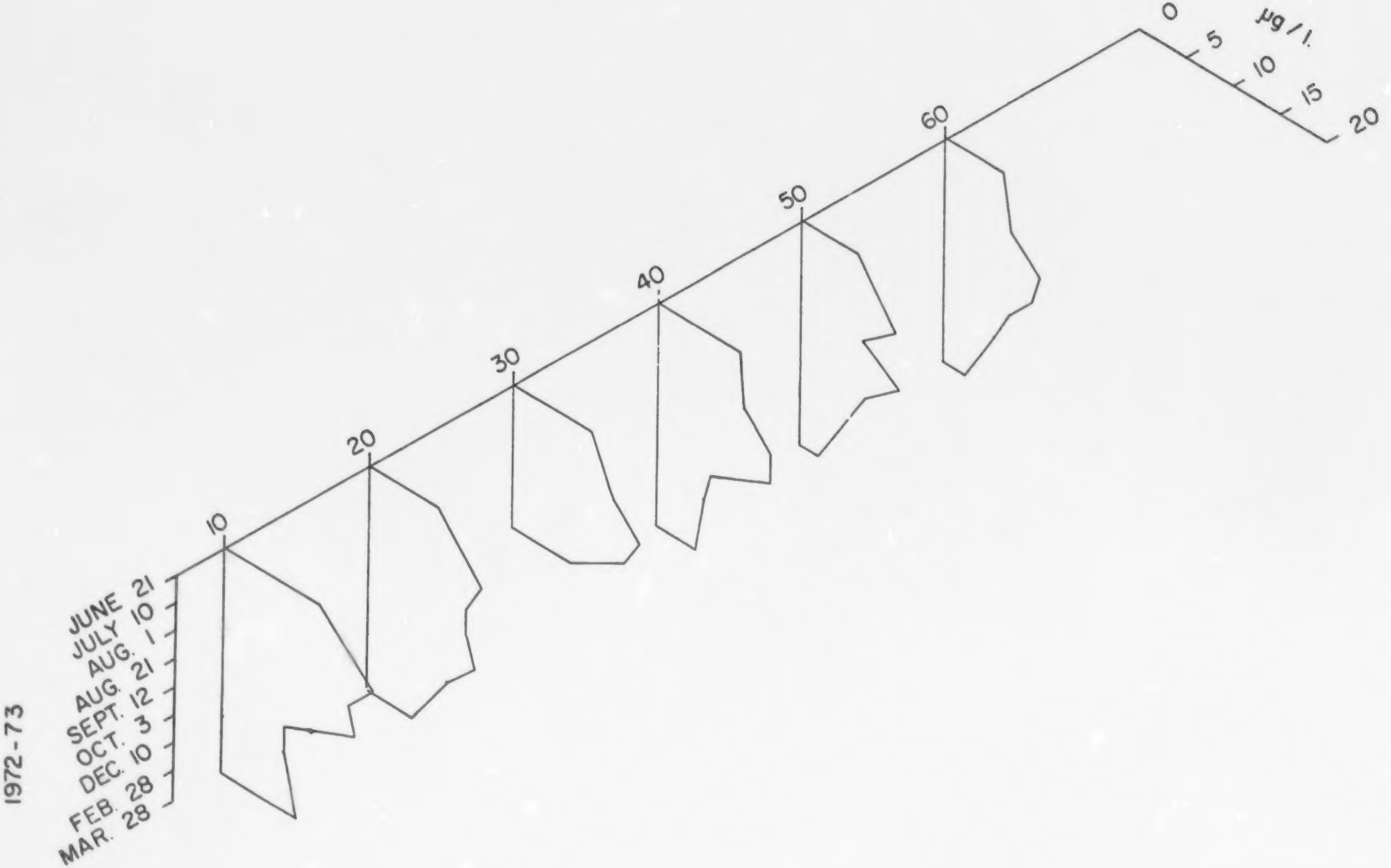


Figure 10 . Suspended phosphorus, Southern Indian Lake.

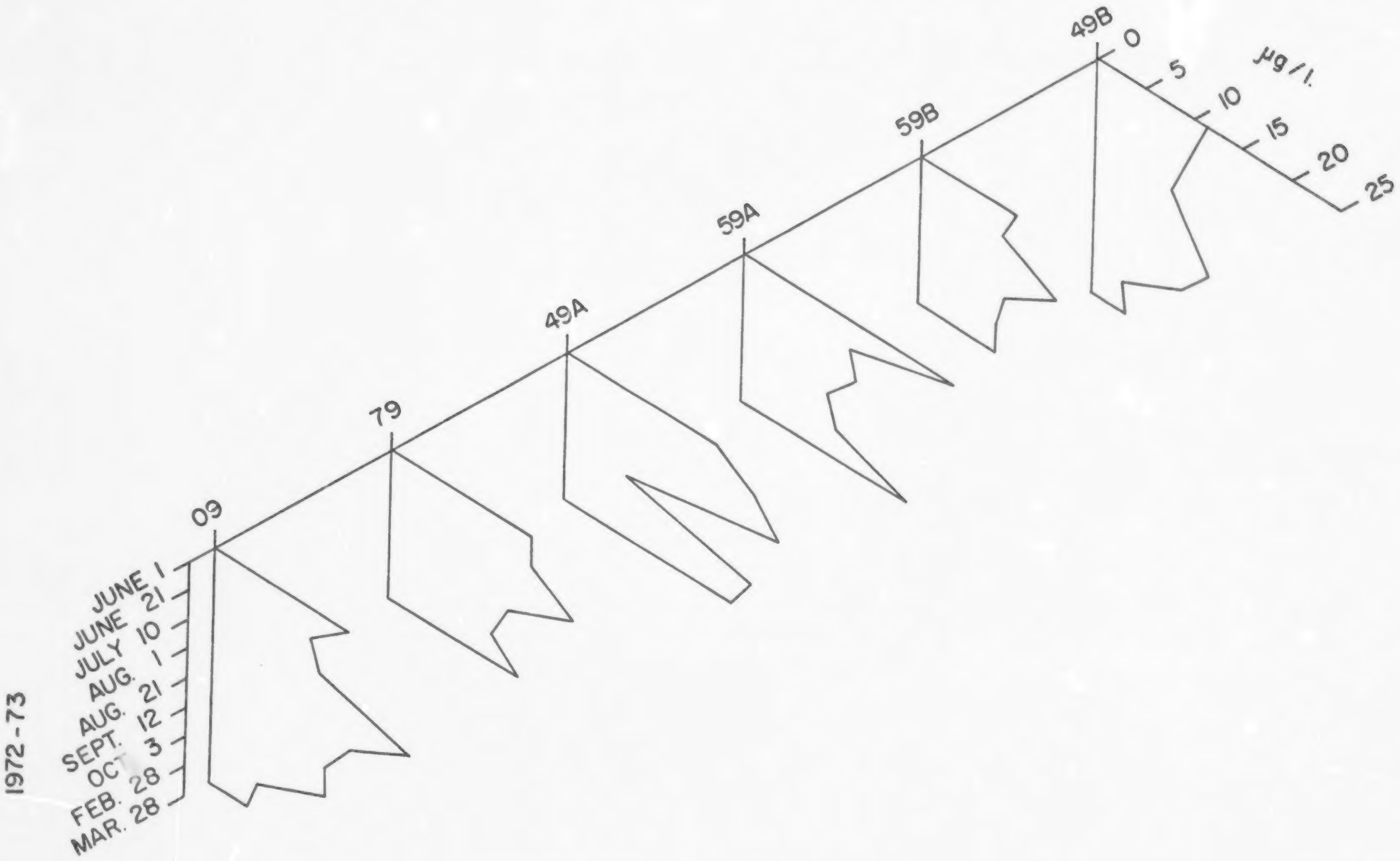
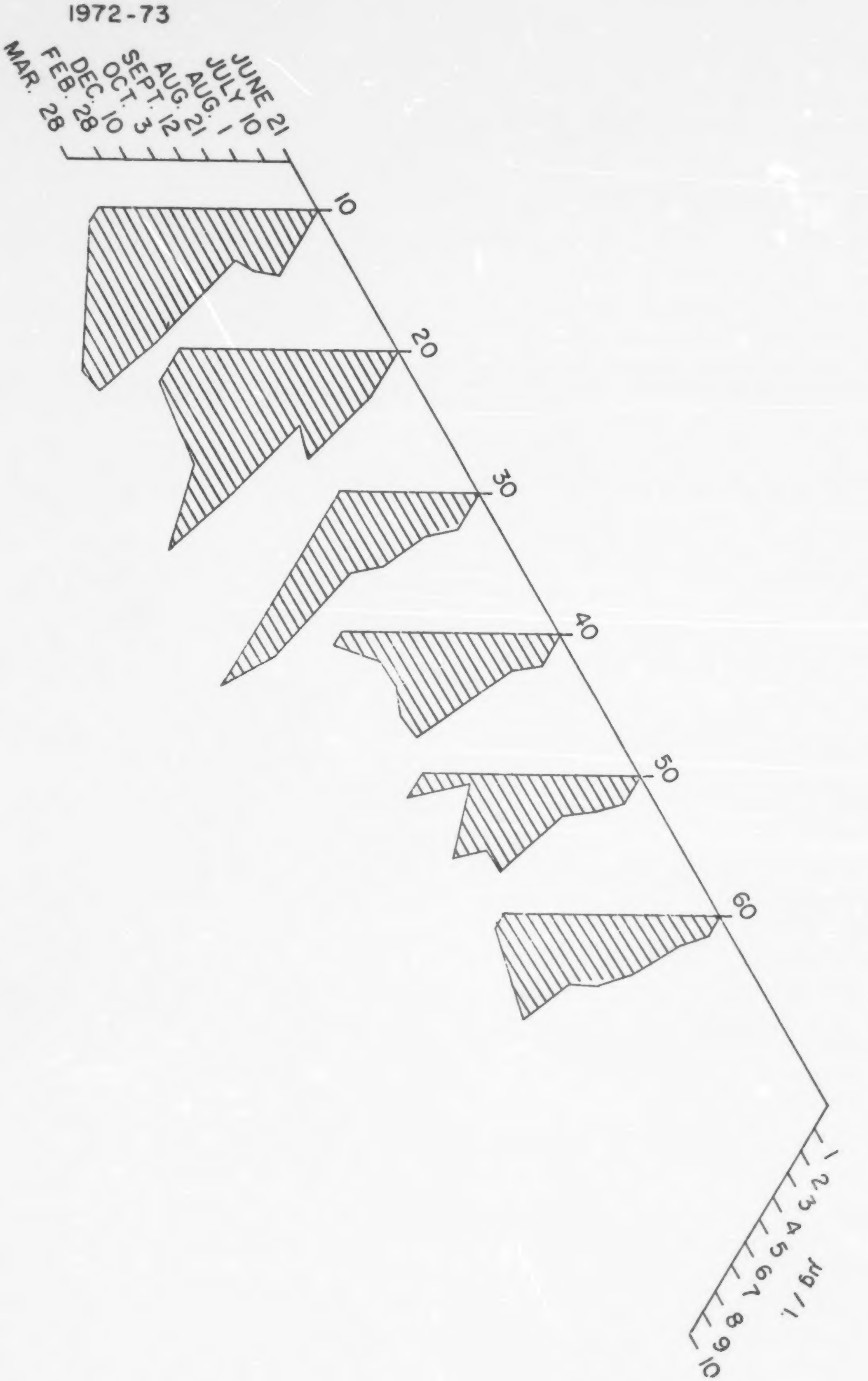


Figure 11 . Suspended phosphorus, Southern Indian Lake.


1972-73
JUNE 21
JULY 10
AUG. 1
AUG. 21
SEPT. 12
OCT. 3
DEC. 10
FEB. 28
MAR. 28
10
20
30
40
50
60
1
2
3
4
5
6
7
8
9
10
µg / l.

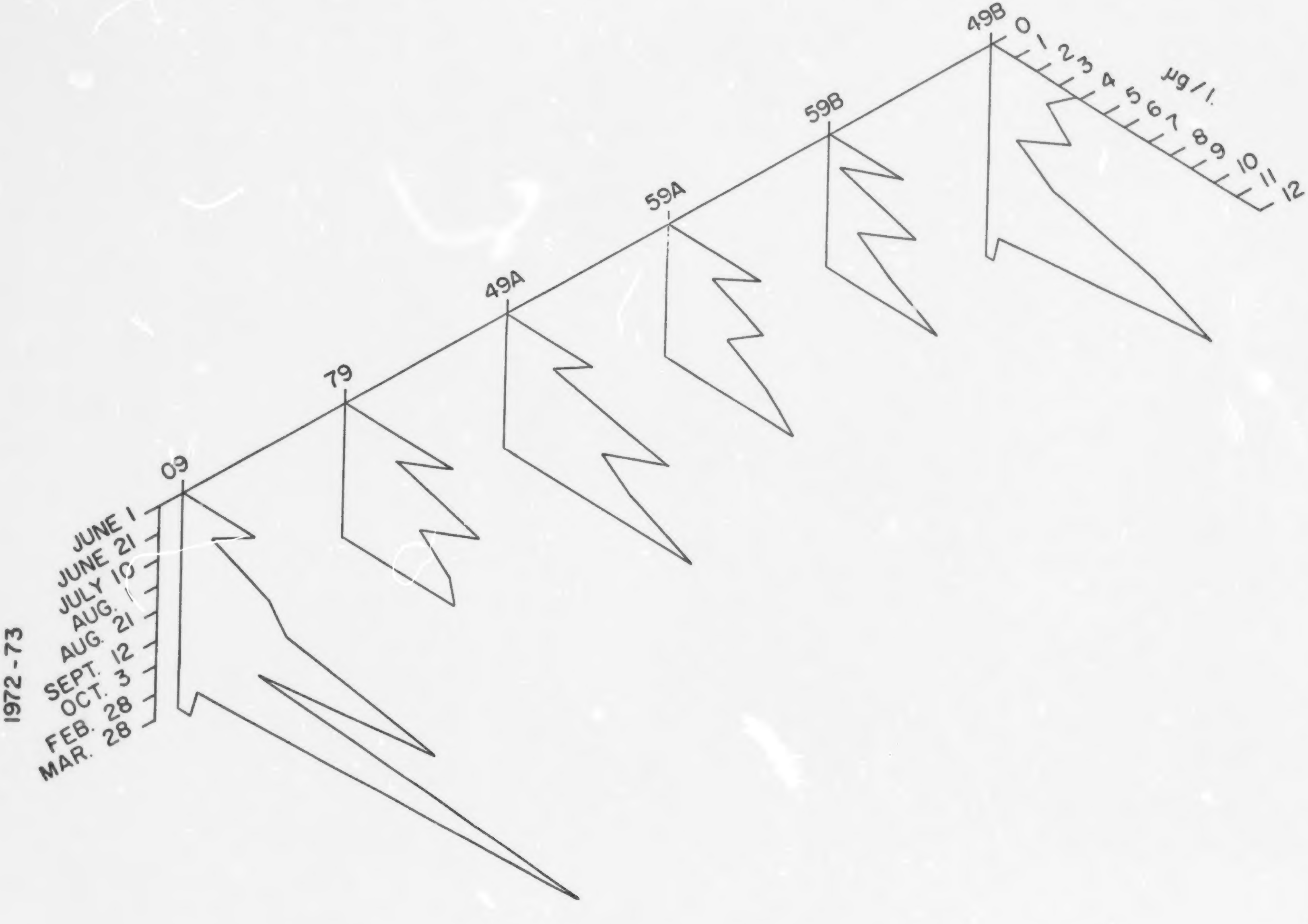
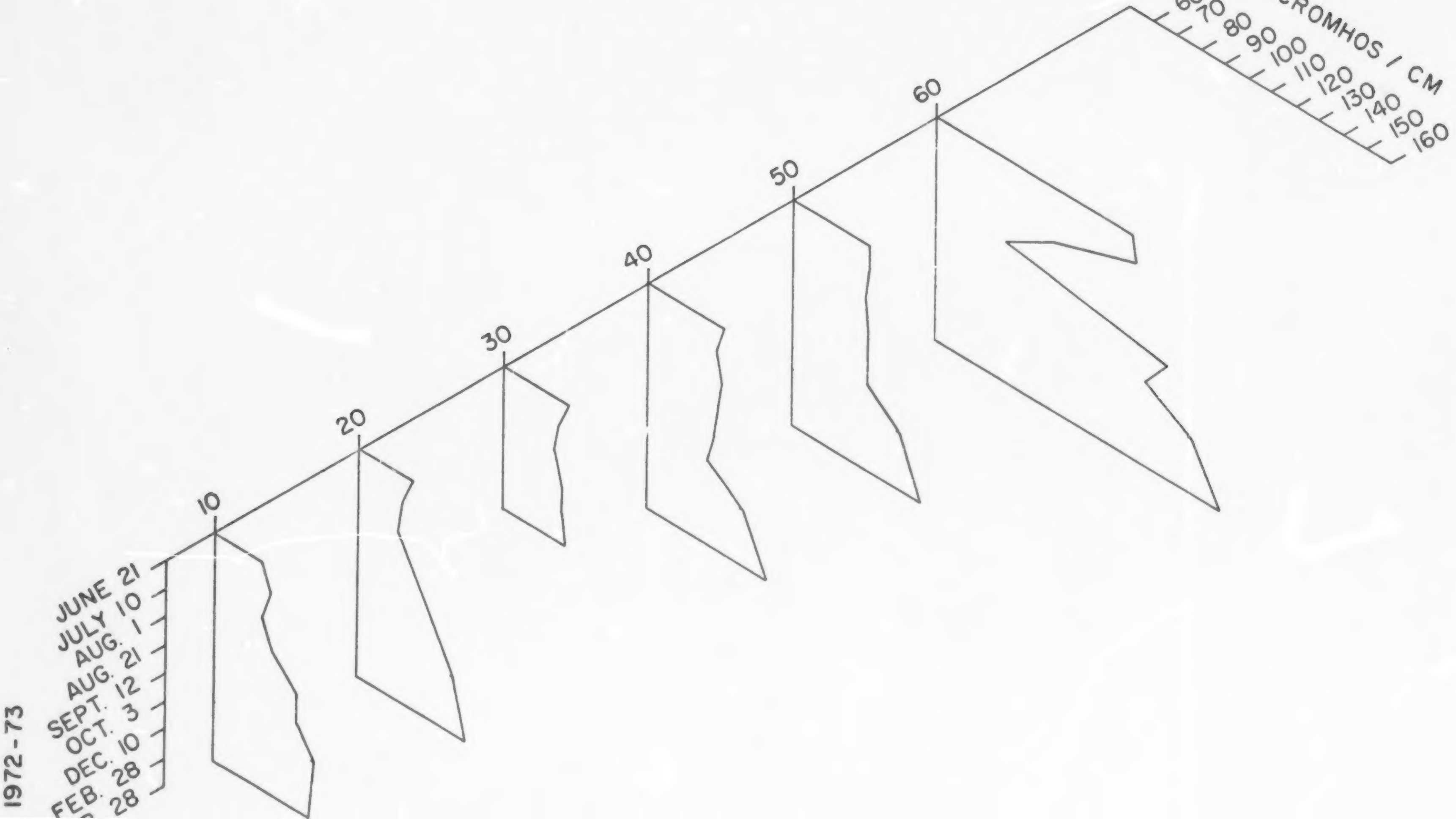


Figure 13 . Chlorophyll a, Southern Indian Lake.


MICROMHOS / CM
60
70
80
90
100
110
120
130
140
150
160
10
20
30
40
50
60
JUNE 21
JULY 10
AUG. 1
AUG. 21
AUG. 12
SEPT. 3
OCT. 10
DEC. 28
FEB. 28
28
1972-73

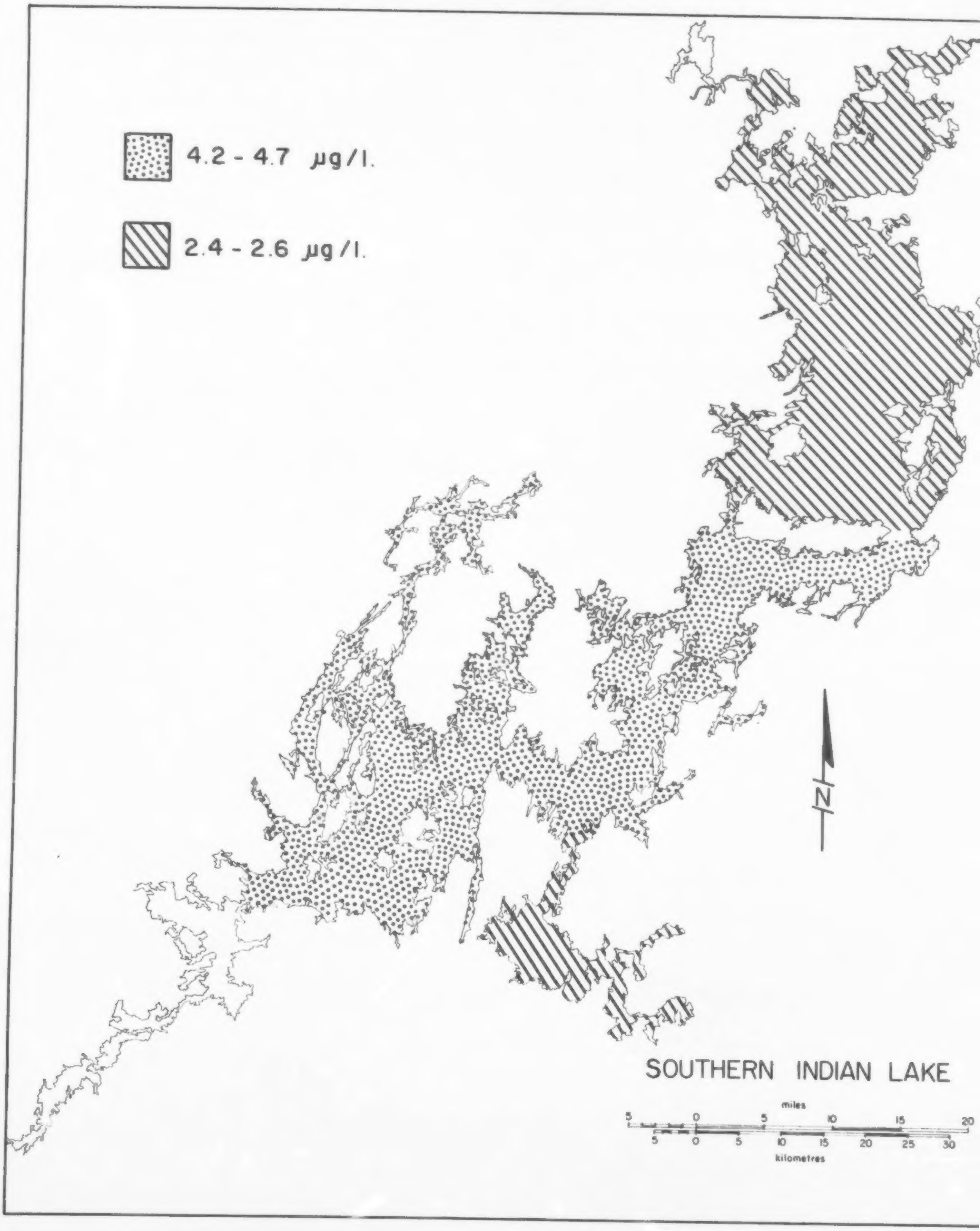

4.2 - 4.7 µg/l.
2.4 - 2.6 µg/l.
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

Figure 14 . Chlorophyll a, June-October 1972.

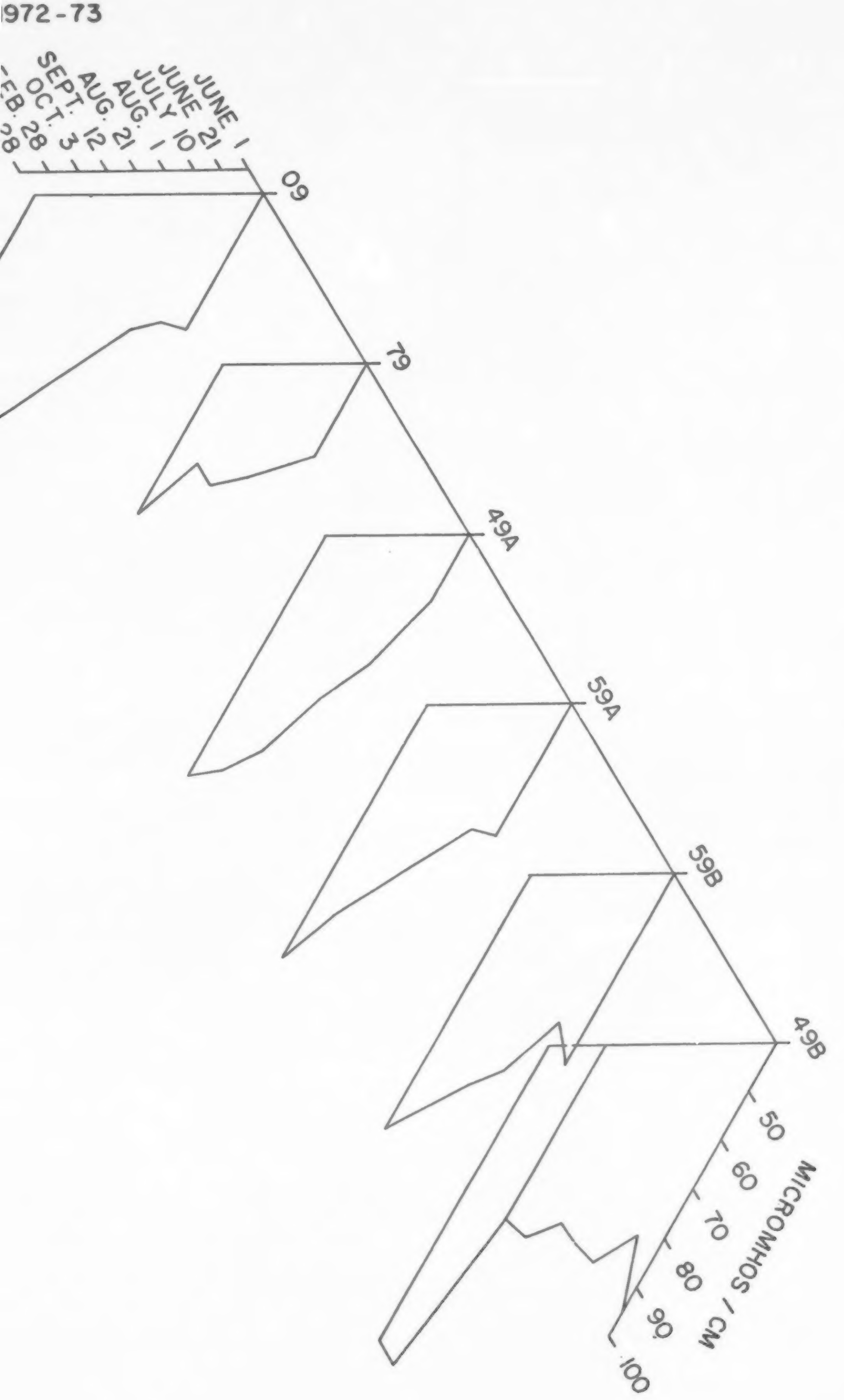

972-73
JUNE 1
JUNE 21
JULY 10
1
AUG. 21
AUG. 12
SEPT. 3
OCT. 28
FEB. 28
09
79
49A
59A
59B
49B
50
60
70
80
90
100
MICROMHOS / CM

Figure 16 . Specific conductance, Southern Indian Lake.

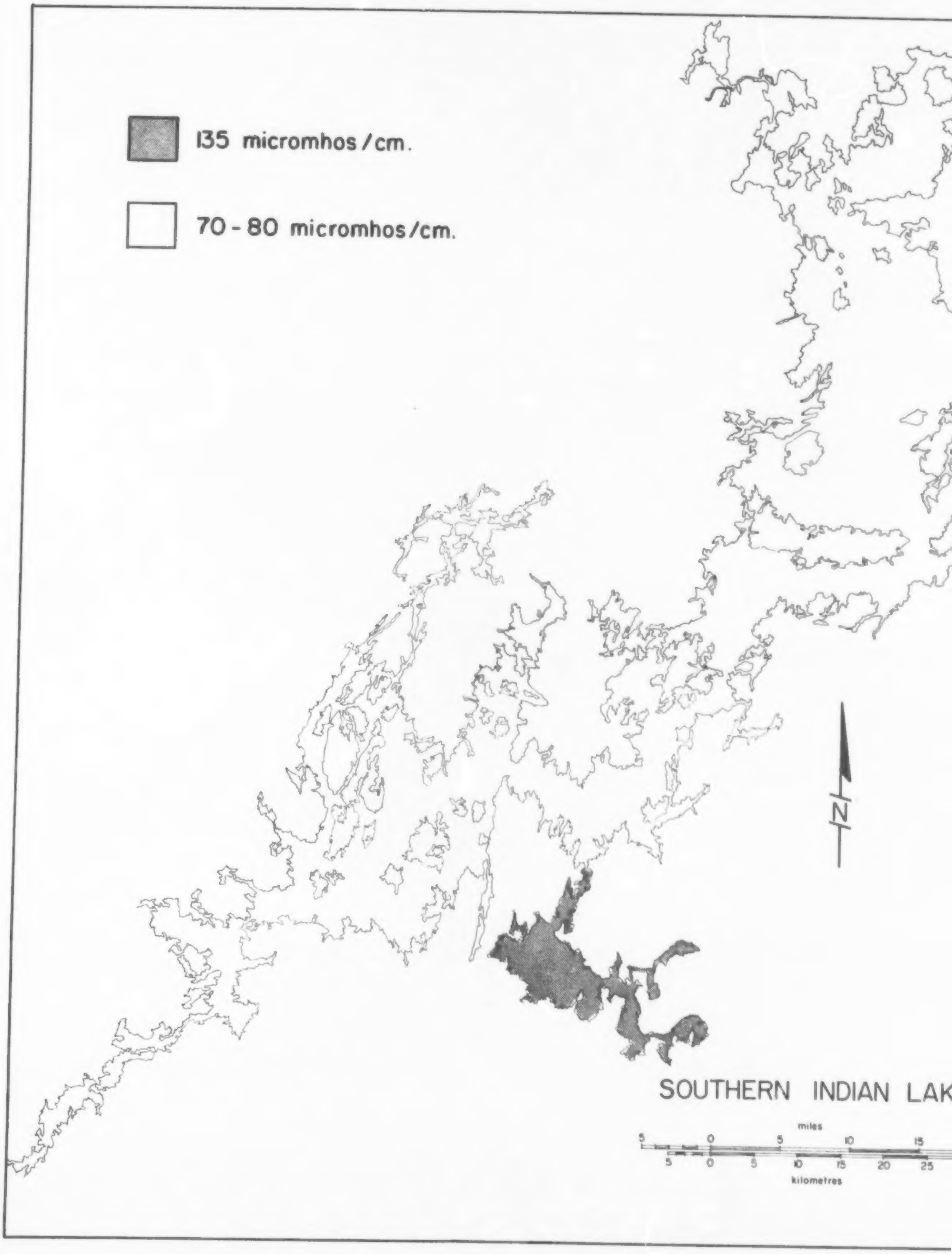

135 micromhos/cm.
70-80 micromhos/cm.
N
SOUTHERN INDIAN LAK
miles
5 0 5 10 15
5 0 5 10 15 20 25
kilometres

Figure 17 . Specific conductance, June-October 1972.

20
30

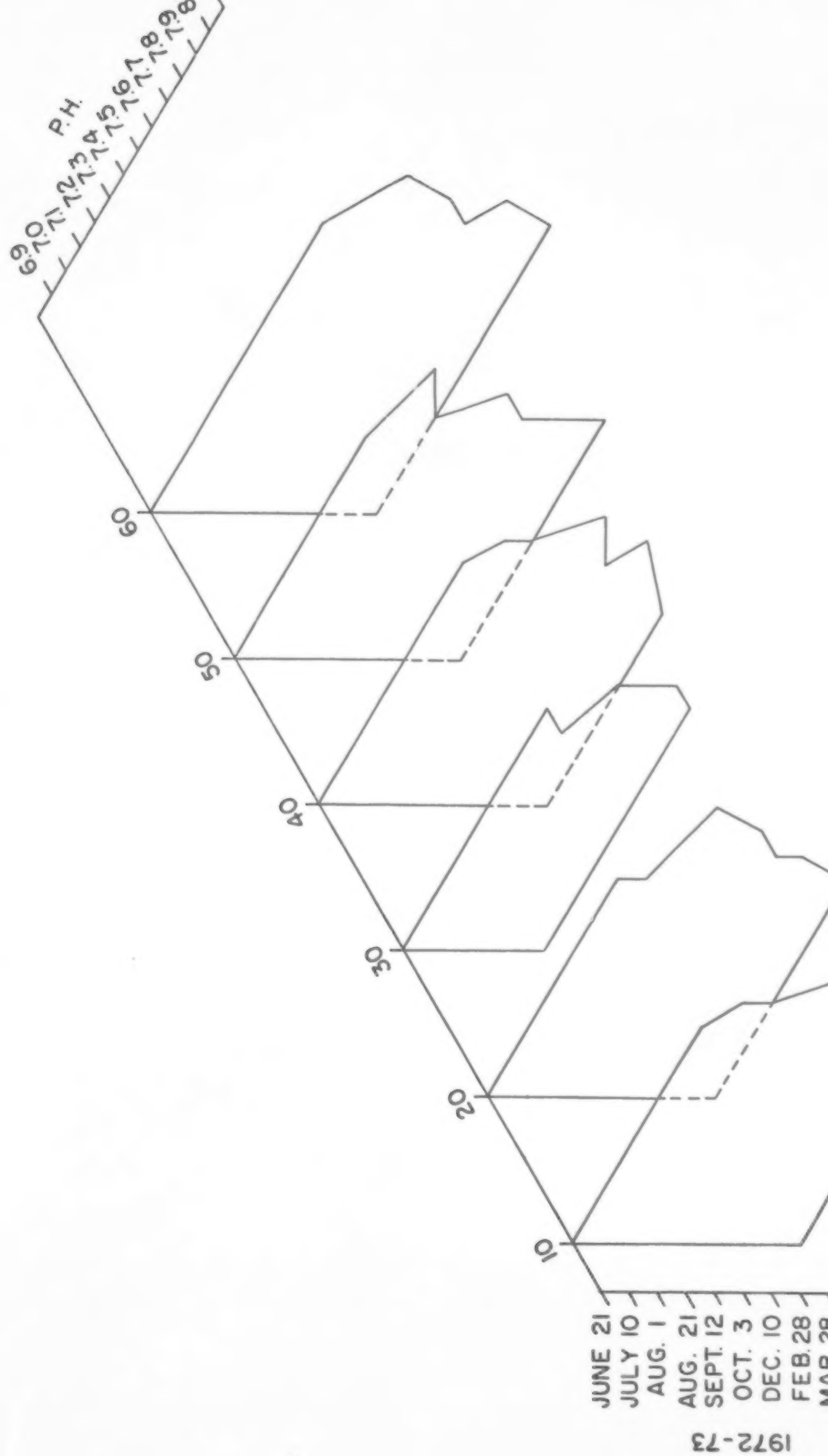

P.H.
6.9
7.0
7.1
7.2
7.3
7.4
7.5
7.6
7.7
7.8
7.9
8.0
8.1
60
50
40
30
20
10
JUNE 21
JULY 10
AUG. 1
AUG. 21
SEPT. 12
OCT. 3
DEC. 10
FEB. 28
1972-73

Figure 18 . Hydrogen ion concentration, Southern Indian Lake.

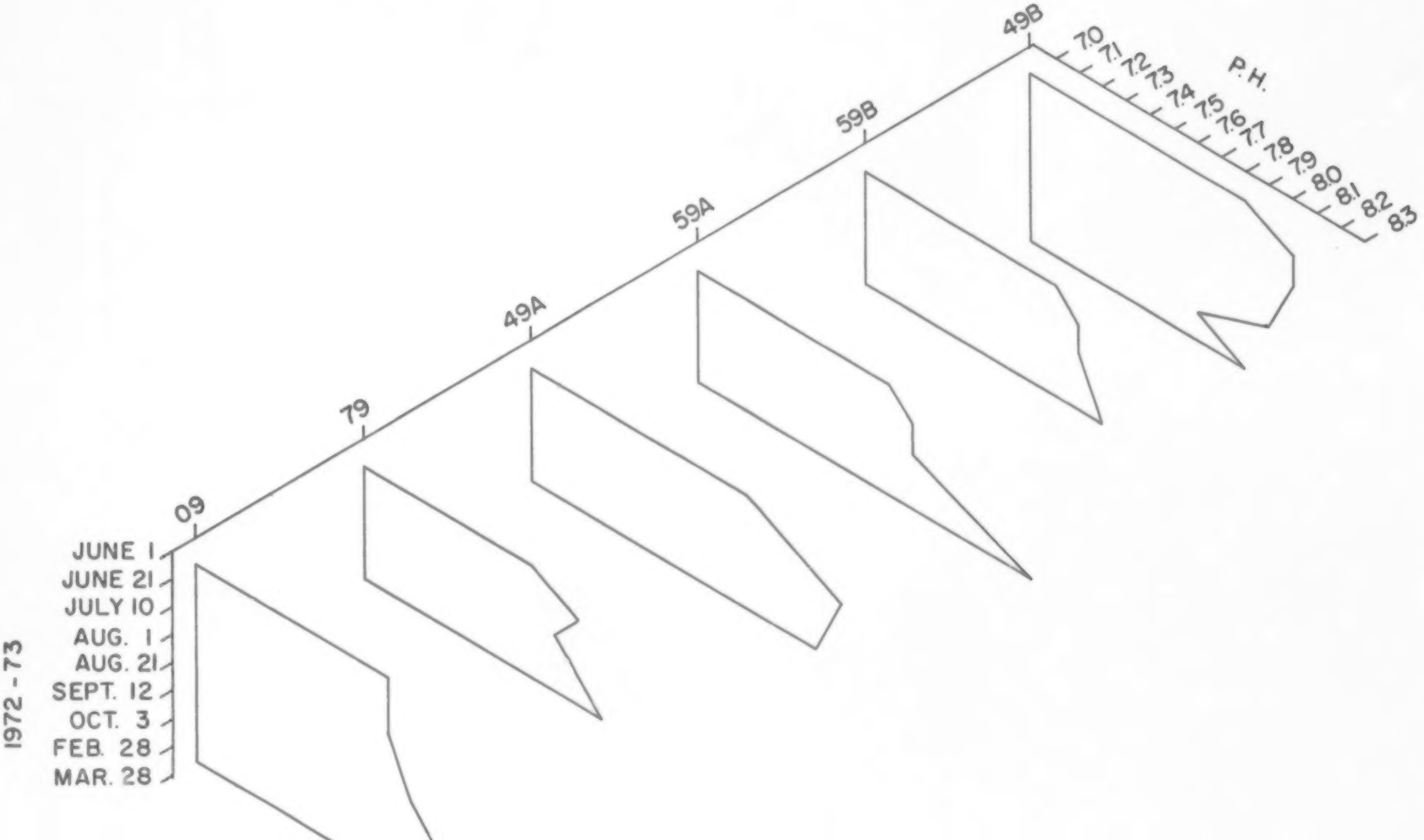


Figure 19 . Hydrogen ion concentration, Southern Indian Lake.

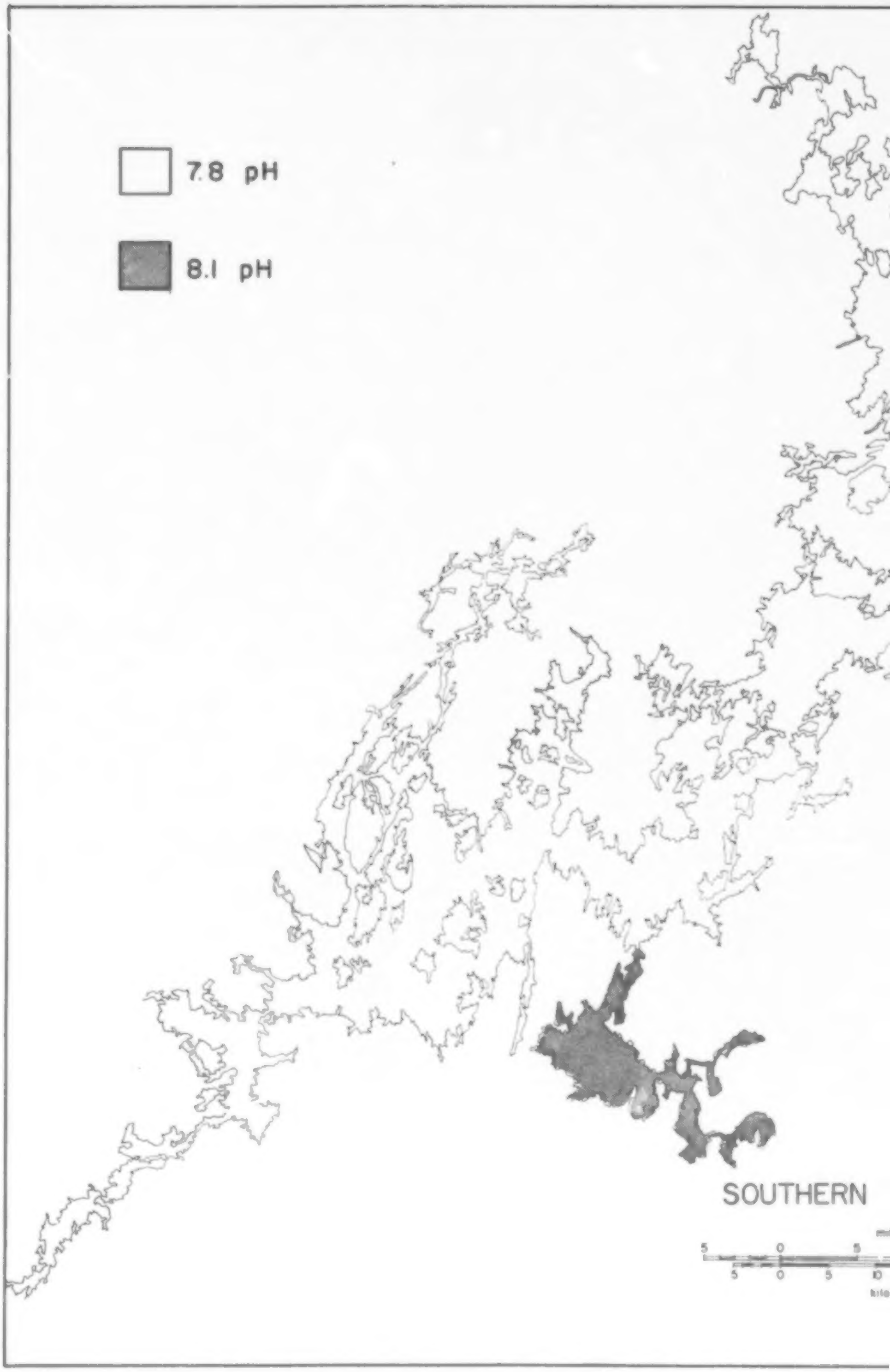

7.8 pH
8.1 pH
SOUTHERN
5 0 5
5 0 5 10

Figure 20 . Hydrogen ion concentration, June-October 1972.

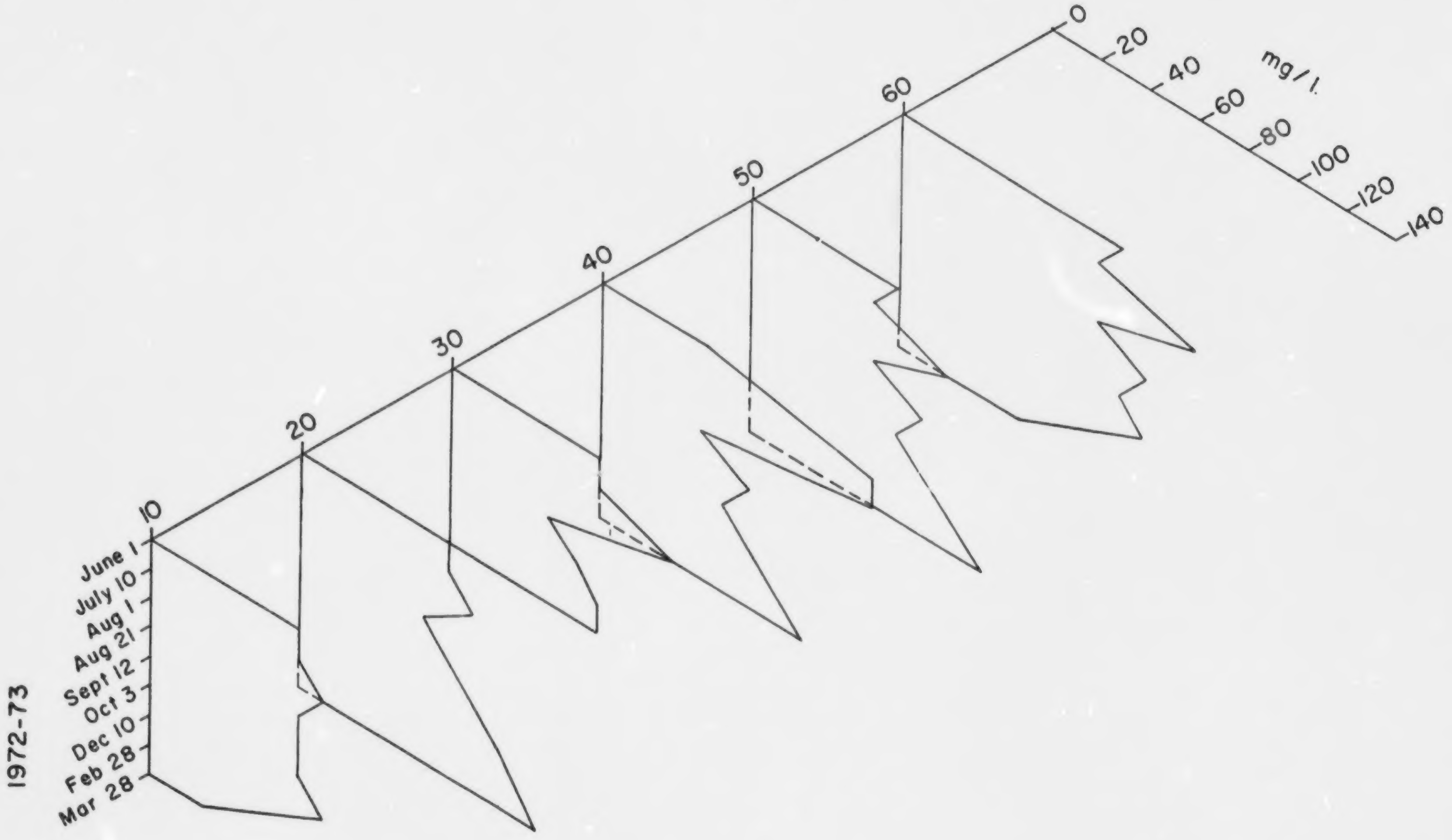


Figure 21 . Total dissolved solids, Southern Indian Lake.

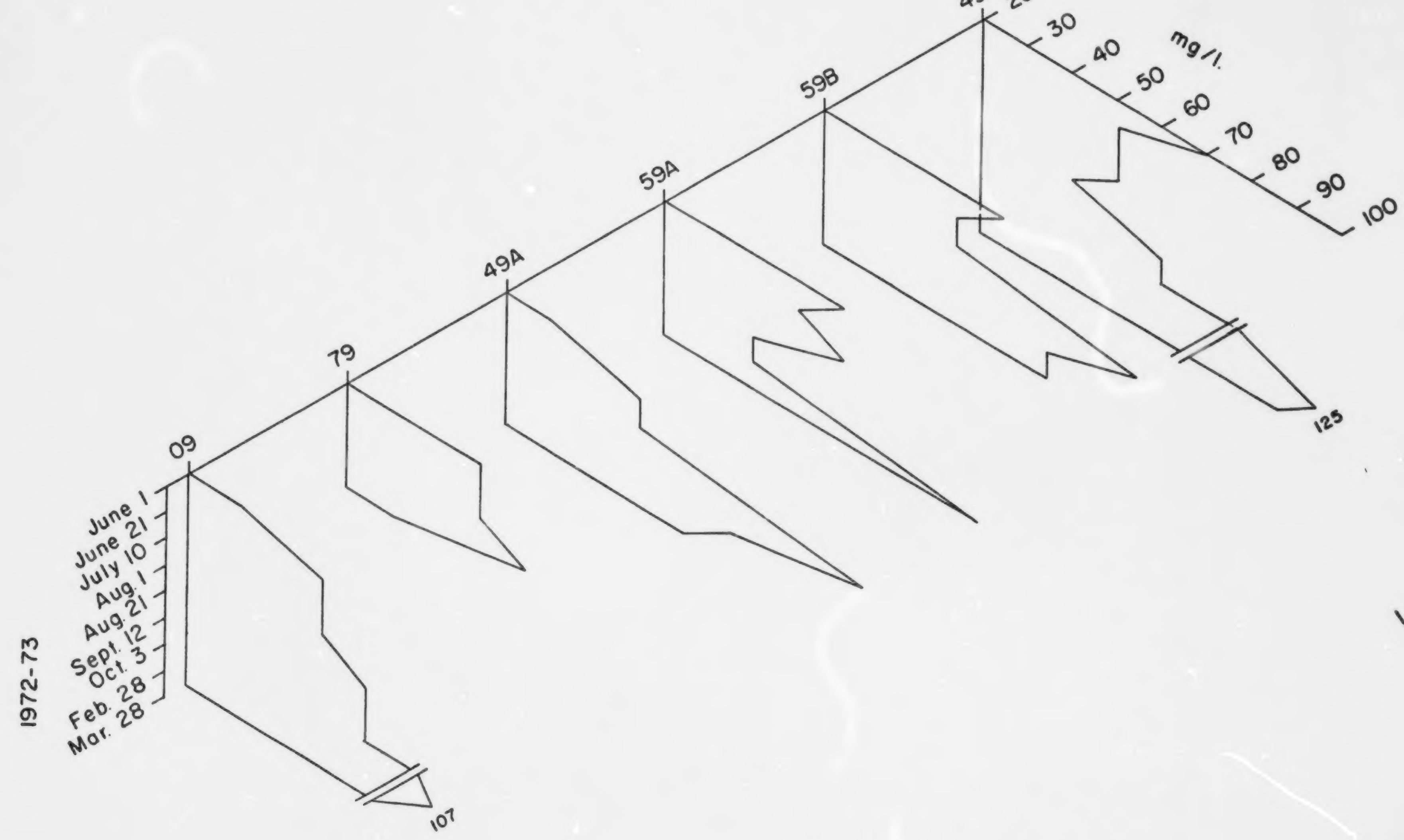


Figure 22 . Total dissolved solids, Southern Indian Lake.

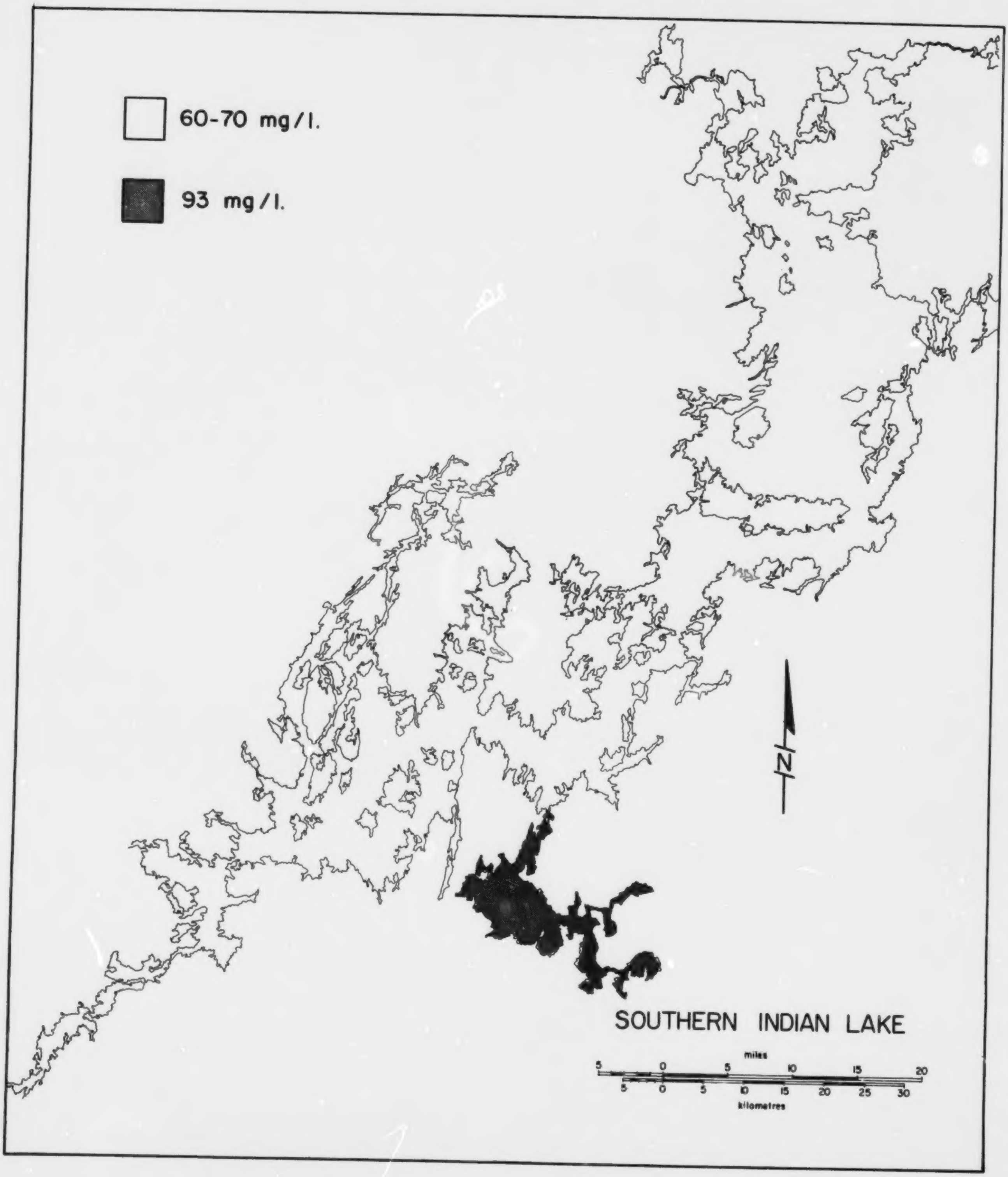

60-70 mg/l.
93 mg/l.
SOUTHERN INDIAN LAKE
miles
5
0
5
10
15
20
5
0
5
10
15
20
25
30
kilometres
N

Figure 25 . Total dissolved solids, June - October, 1972.

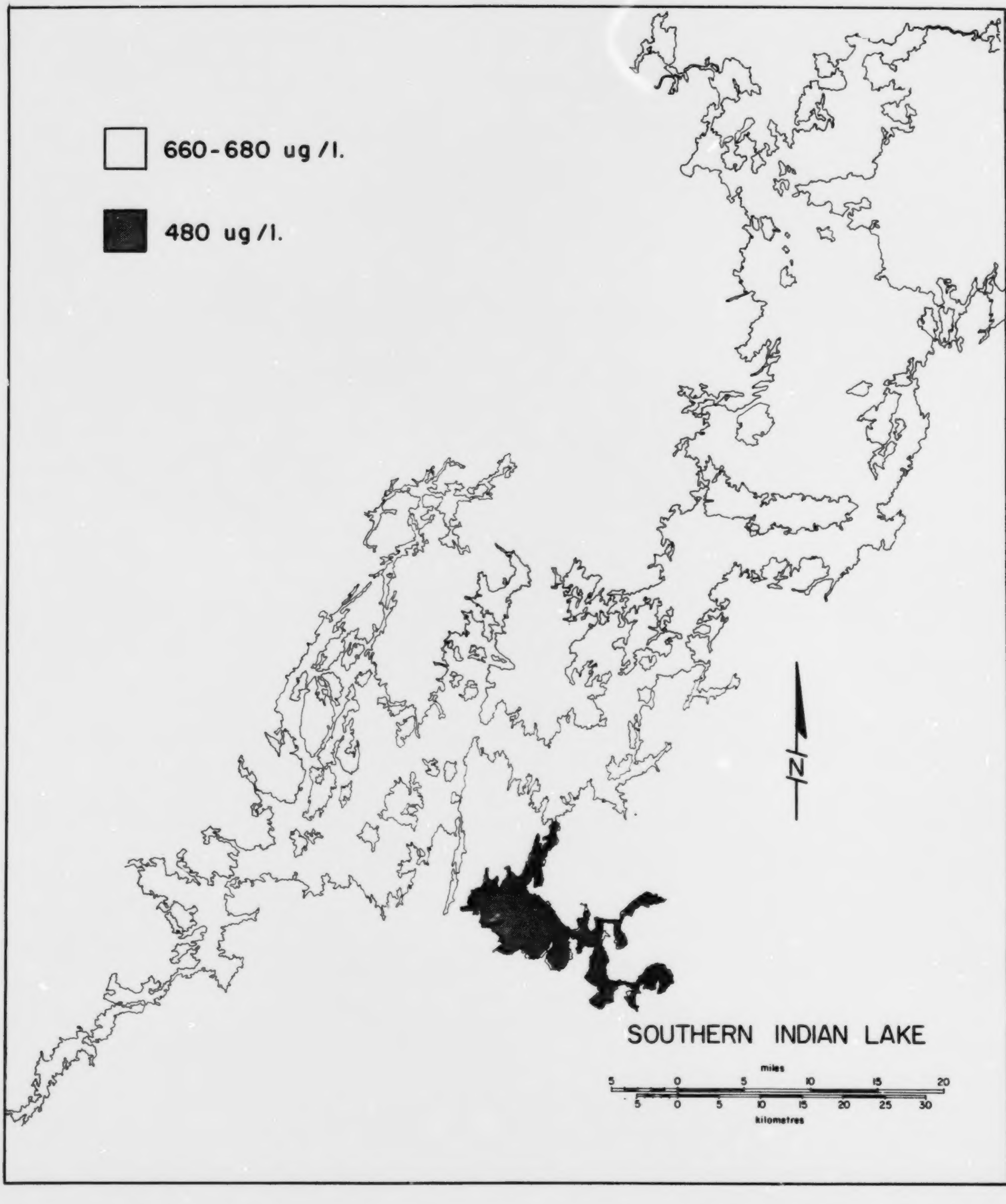

660-680 ug/l.
480 ug/l.
N
SOUTHERN INDIAN LAKE
miles
5
0
5
10
15
20
5
0
5
10
15
20
25
30
kilometres

Figure 24 . Suspended carbon, June-October 1972.

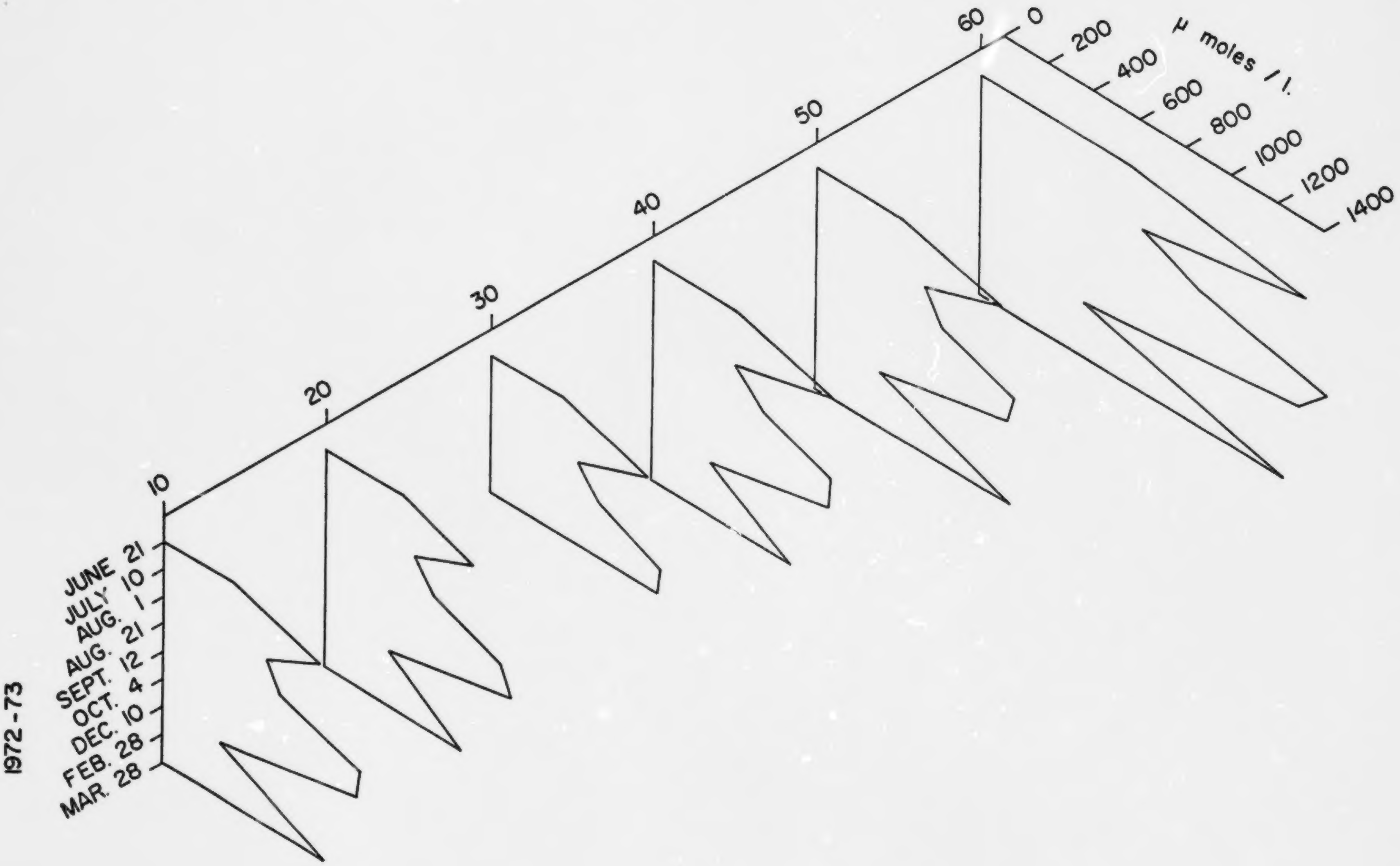


Figure 25 . Total carbon dioxide, Southern Indian Lake.

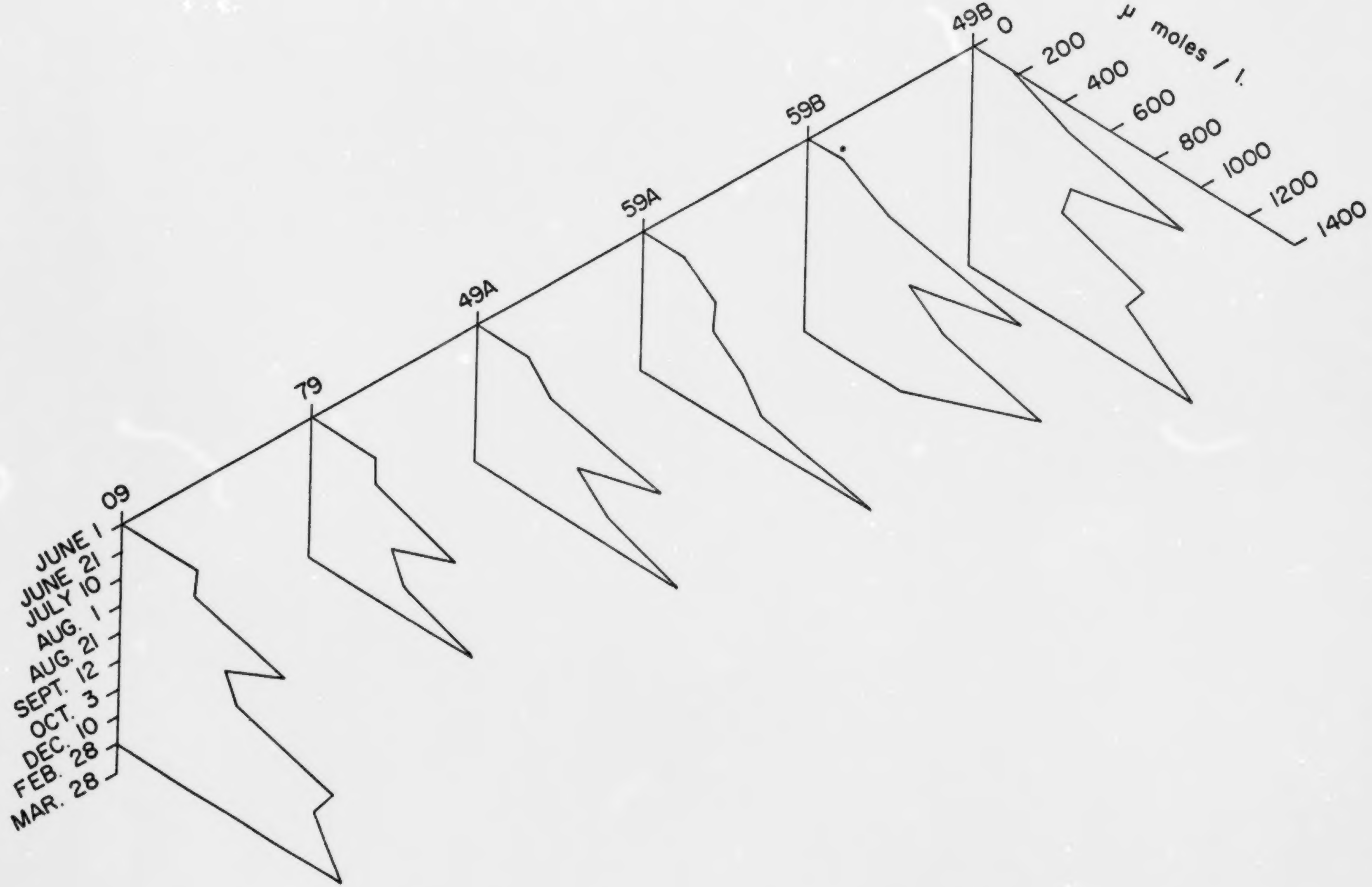


Figure 26. Total

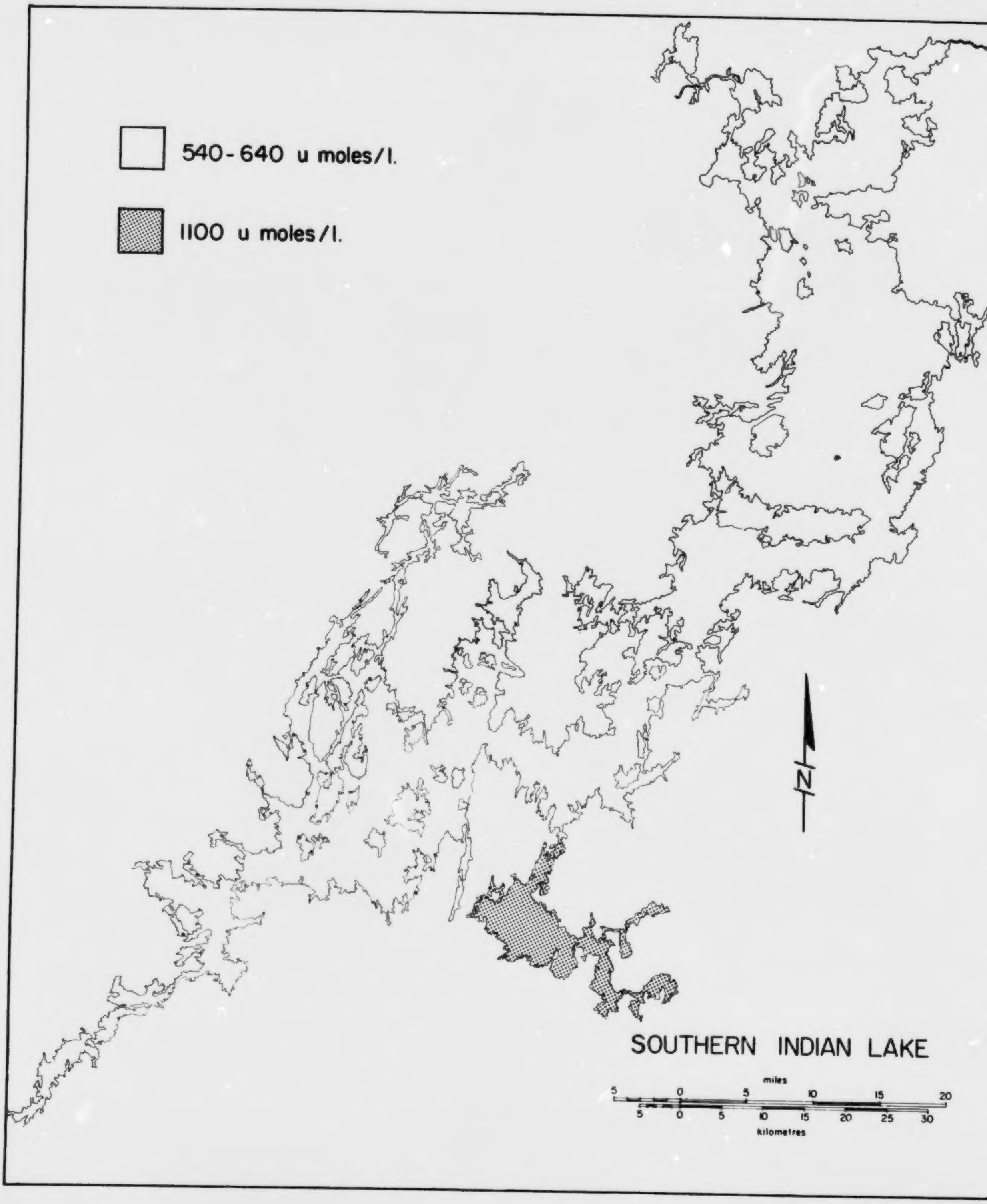

540-640 u moles/l.
1100 u moles/l.
N
SOUTHERN INDIAN LAKE
miles
5
0
5
10
15
20
5
0
5
10
15
20
25
30
kilometres

Figure 27 . Total carbon dioxide, June-October 1972.

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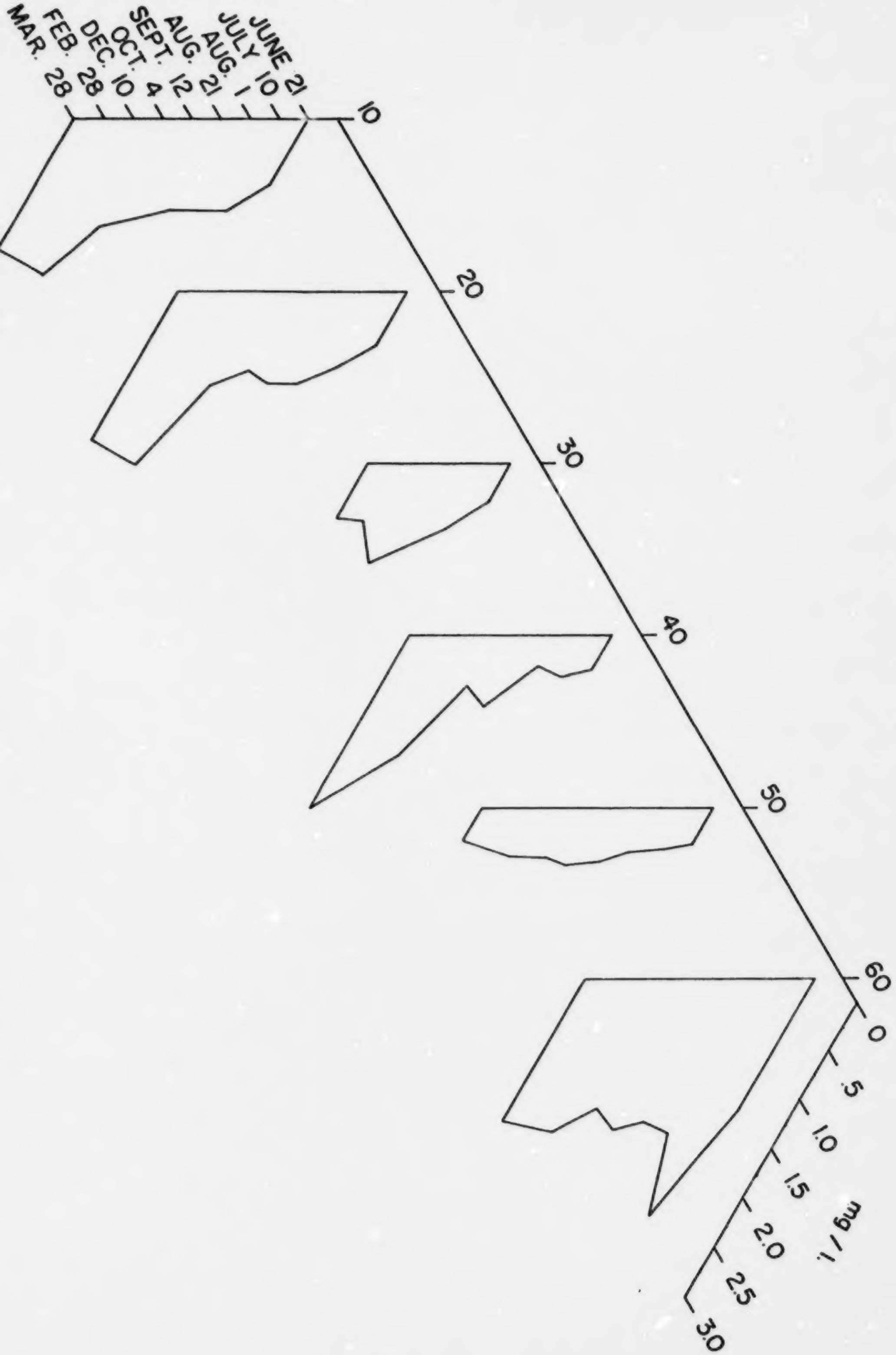

JUNE 21
JULY 10
AUG. 1
AUG. 21
AUG. 12
SEPT. 4
OCT. 10
DEC. 28
FEB. 28
MAR. 28
10
20
30
40
50
60
0
.5
1.0
1.5
2.0
2.5
3.0
mg / l.

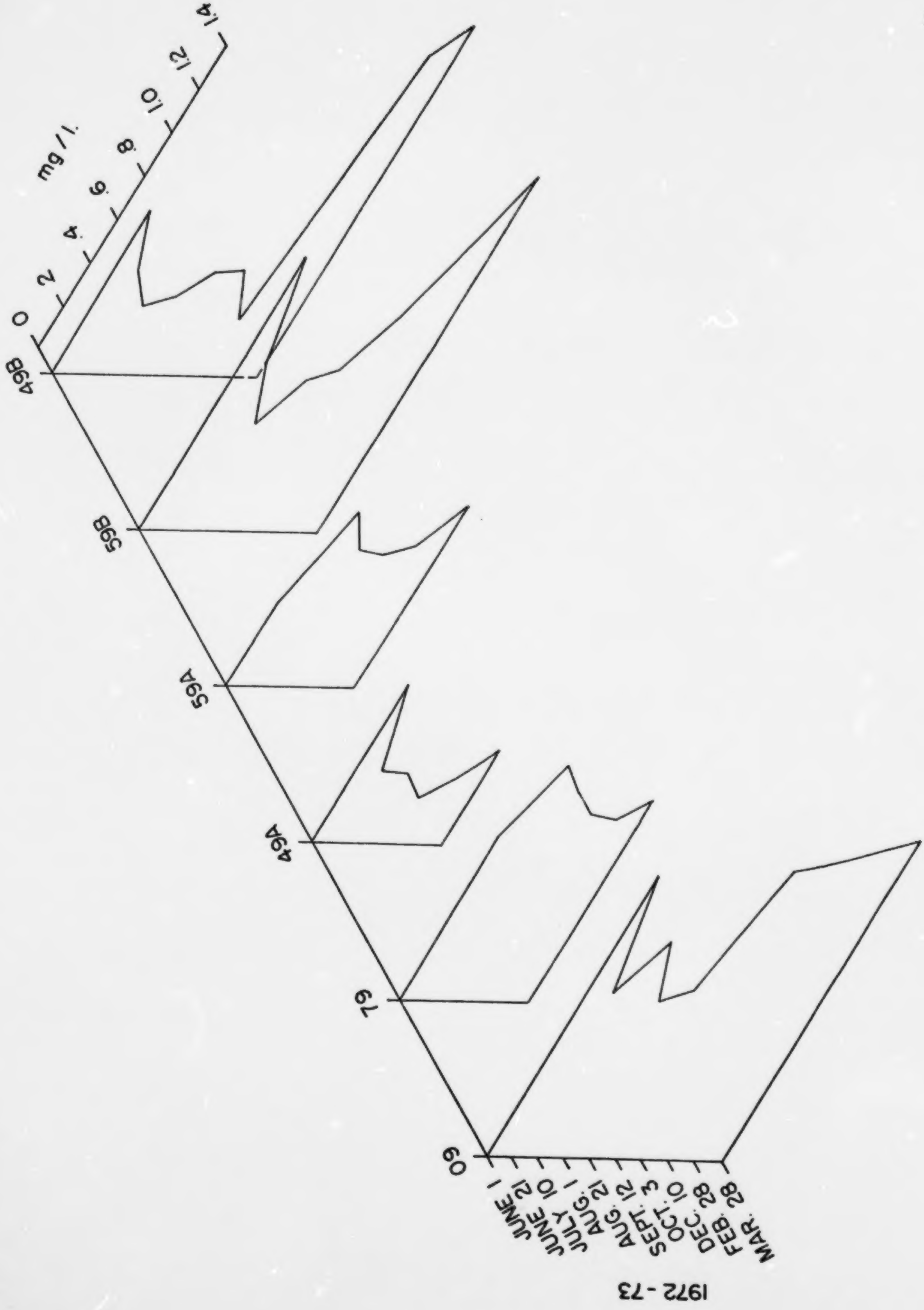
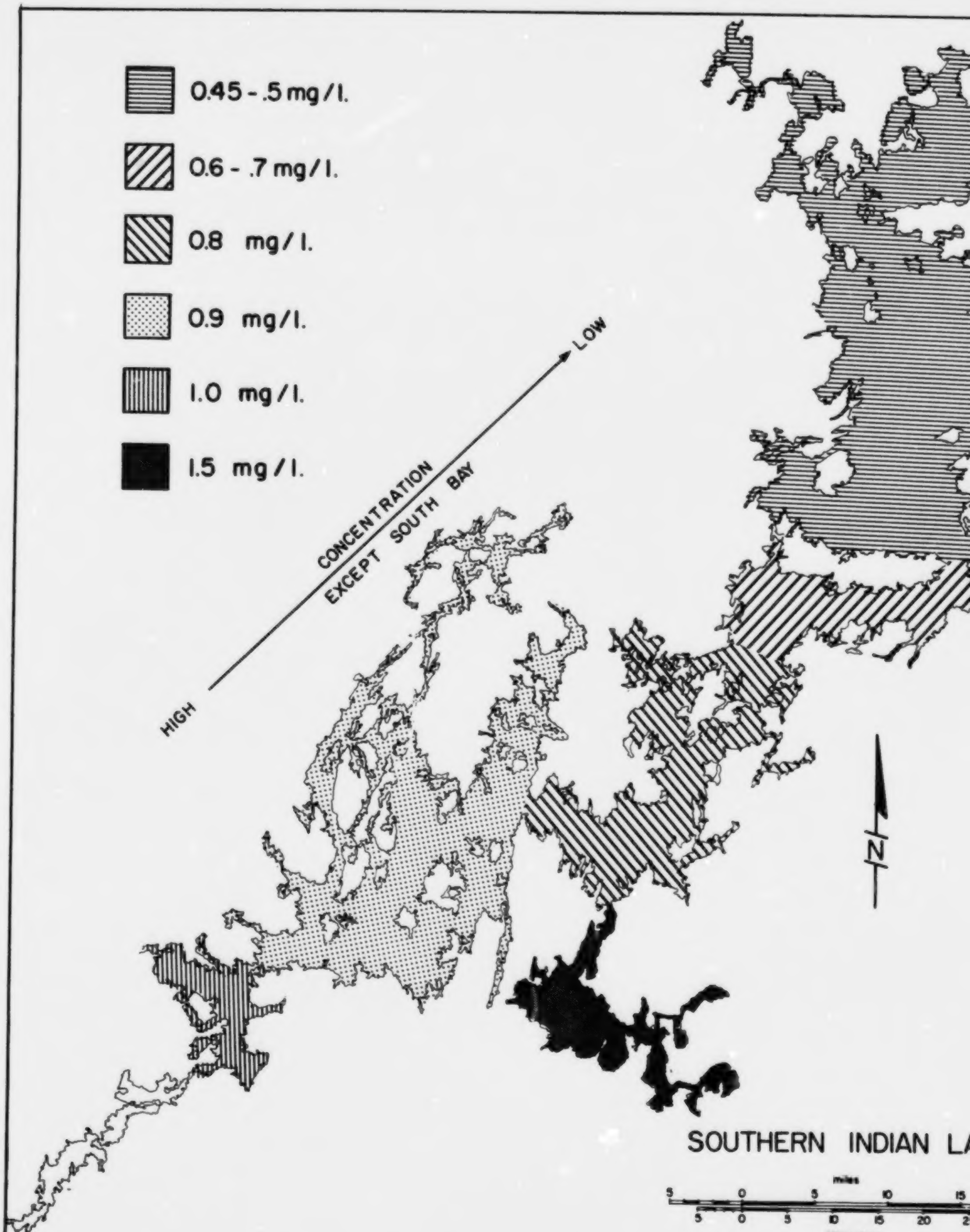

mg / l.
0
2
4
6
8
10
12
14
49B
59B
59A
49A
79
09
JUNE 1
JUNE 21
JULY 10
JULY 1
AUG. 21
AUG. 12
SEPT. 3
OCT. 10
DEC. 28
FEB. 28
MAR. 28
1972 - 73

Figure 29 . Silica, Southern Indian Lake.



▤ 0.45 - .5 mg/l.
▨ 0.6 - .7 mg/l.
▧ 0.8 mg/l.
░ 0.9 mg/l.
▥ 1.0 mg/l.
■ 1.5 mg/l.
HIGH
CONCENTRATION
EXCEPT SOUTH BAY
LOW
N
SOUTHERN INDIAN LA
miles
5 0 5 10 15
5 0 5 10 15 20 2
kilometres

Figure 30 . Silica, June-October 1972.

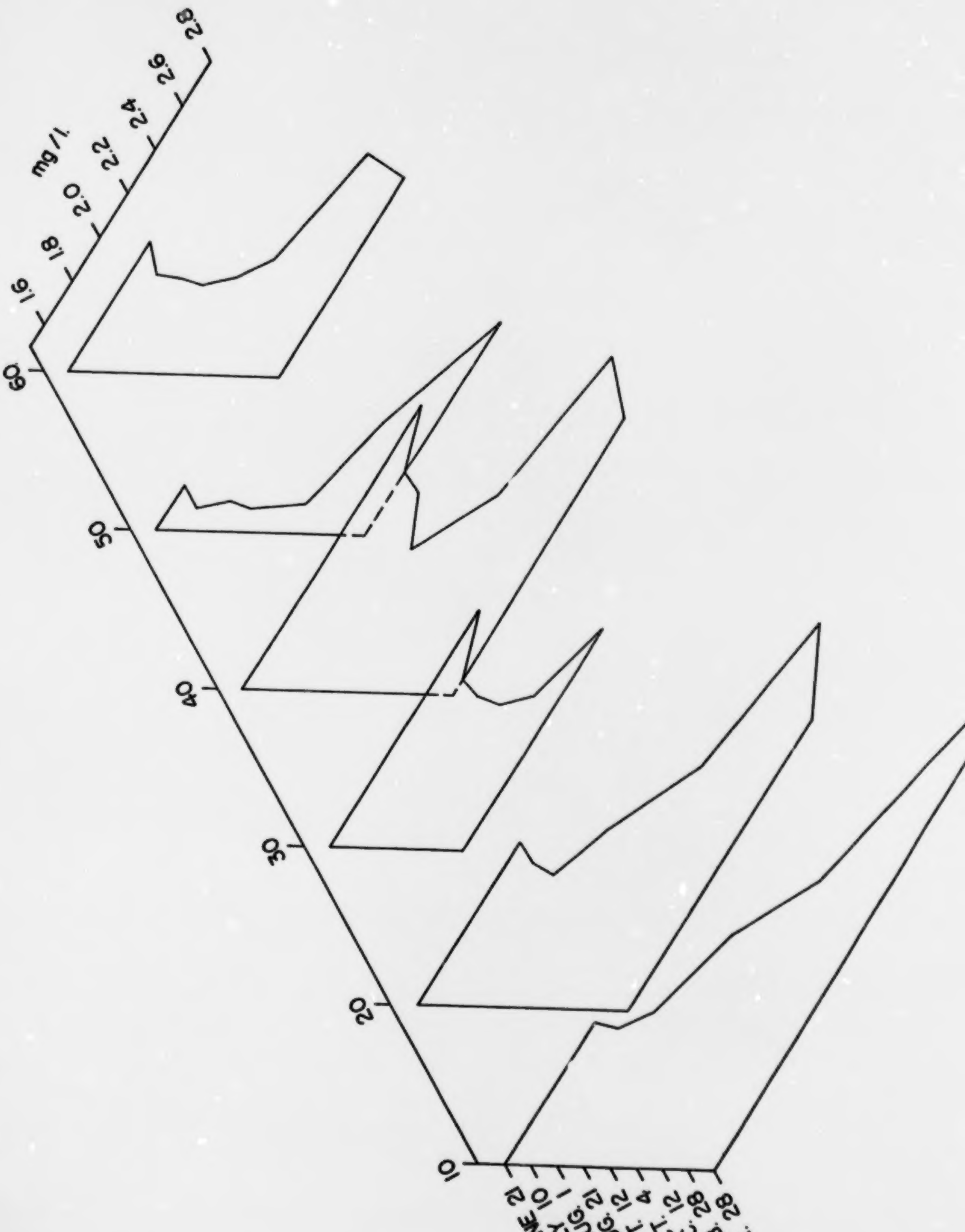

mg/l
1.6
1.8
2.0
2.2
2.4
2.6
2.8
60
50
40
30
20
10
JUNE 21
JULY 10
JULY 1
AUG. 21
AUG. 12
SEPT. 4
OCT. 12
DEC. 28
FEB. 28
MAR. 28
1972-73

Figure 31 . Sodium, Southern Indian Lake.

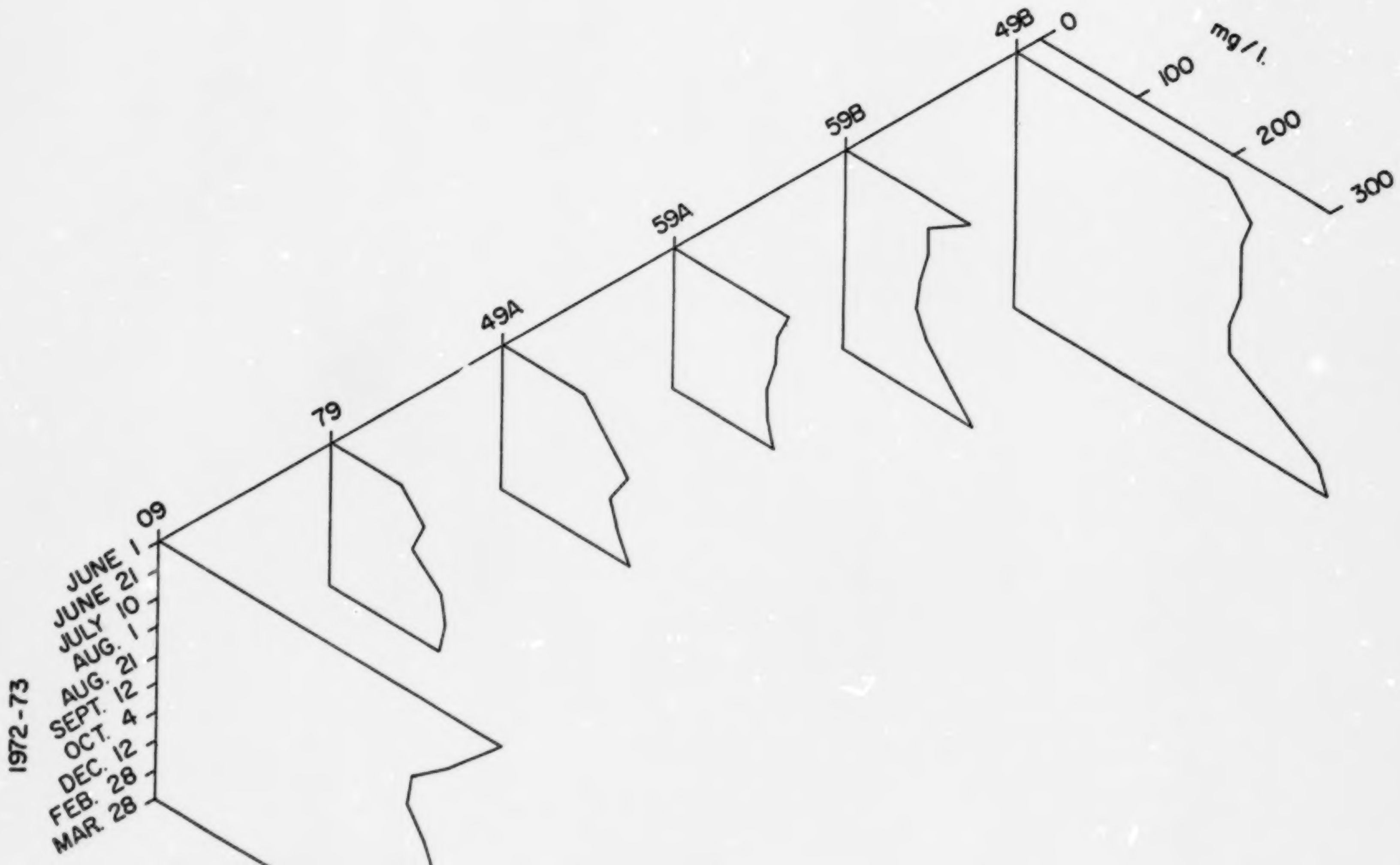
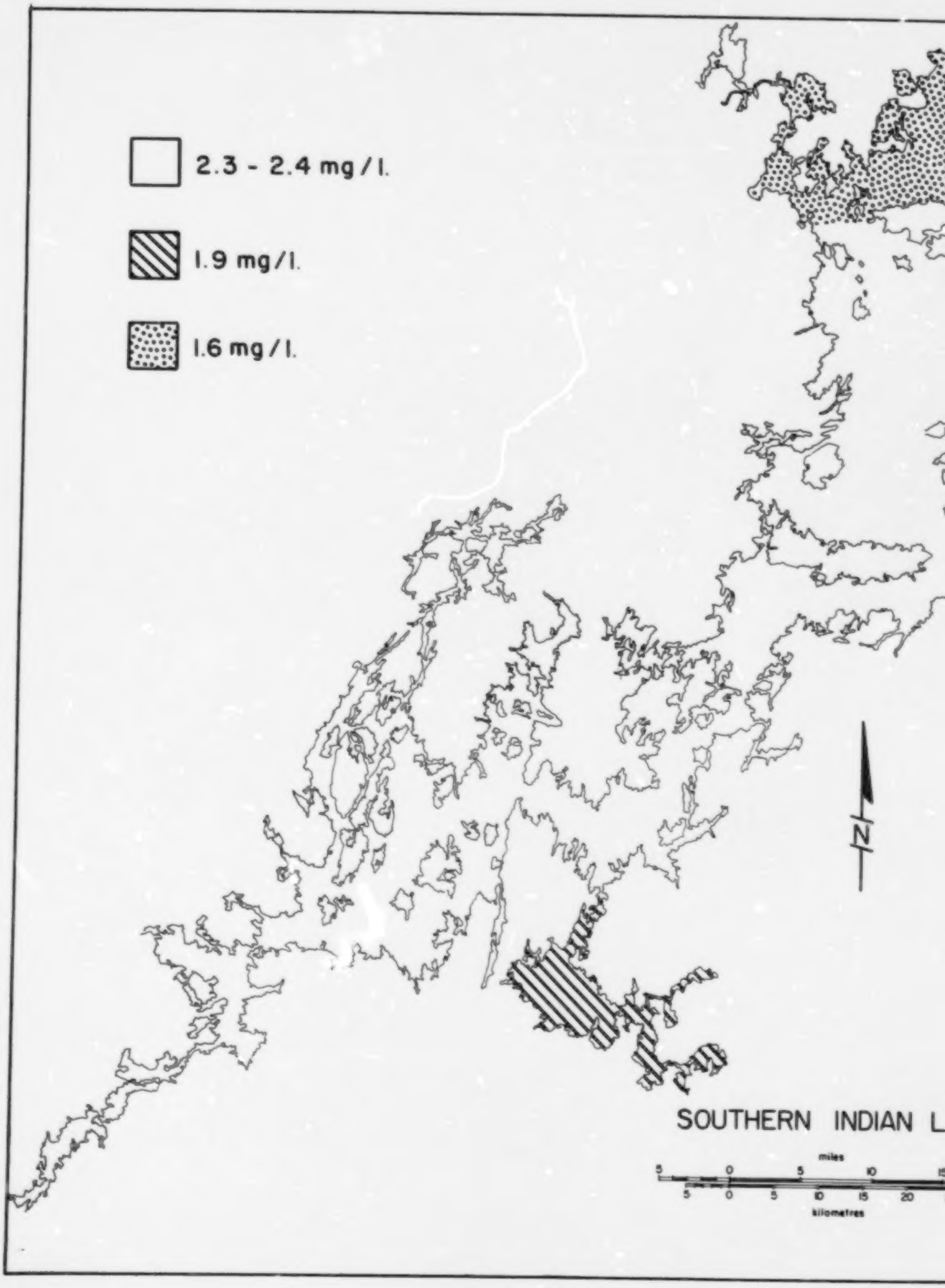


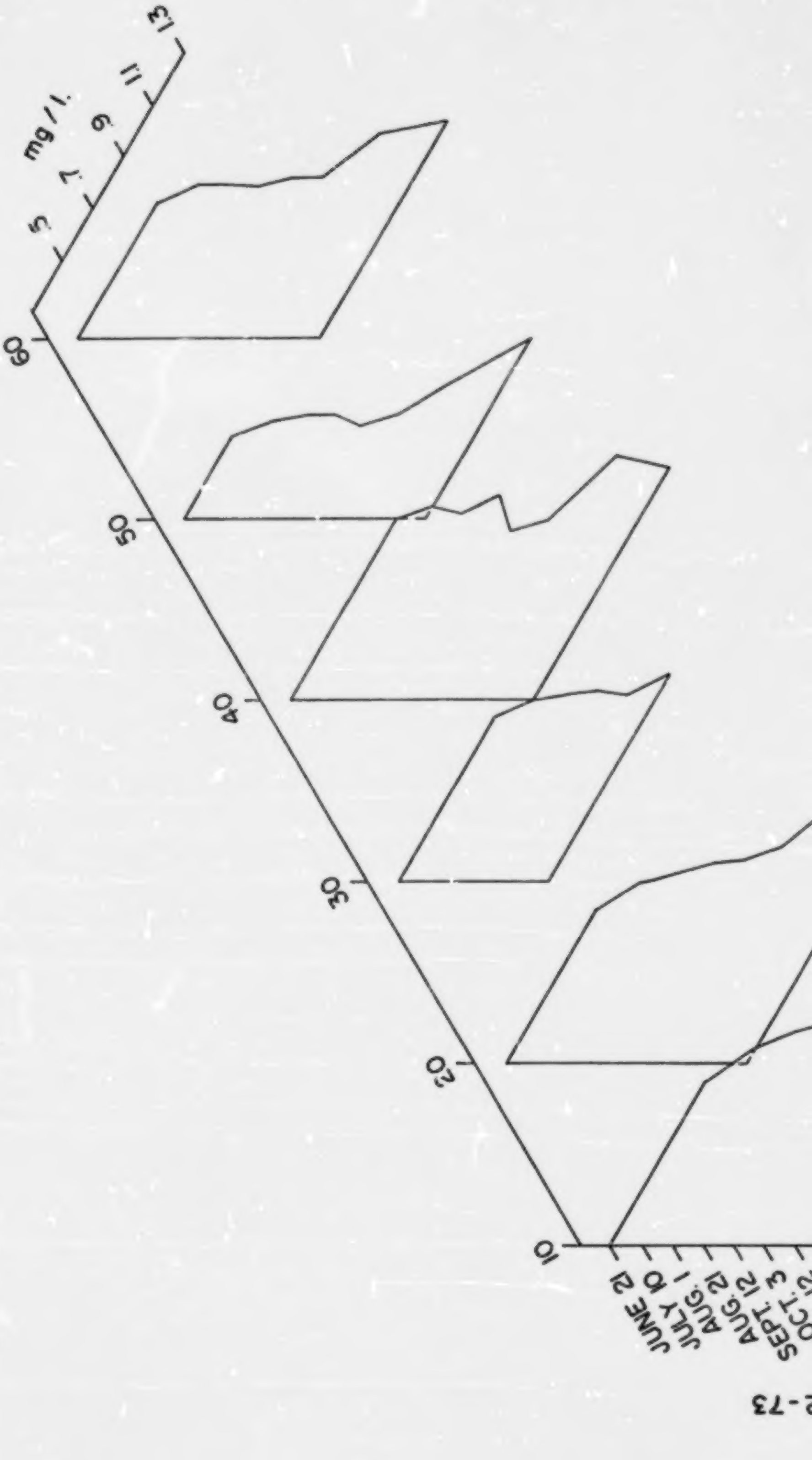
Figure 32 . Sodium, Southern Indian Lake.



2.3 - 2.4 mg/l.
1.9 mg/l.
1.6 mg/l.
N
SOUTHERN INDIAN L
miles
5 0 5 10 15
5 0 5 10 15 20
kilometres

Figure 33 . Sodium, June-October 1972.

AKE
20
30


mg/l.
5
7
9
11
13
60
50
40
30
20
10
JUNE 21
JULY 10
AUG. 1
AUG. 21
AUG. 12
SEPT. 3
OCT. 12

2-73

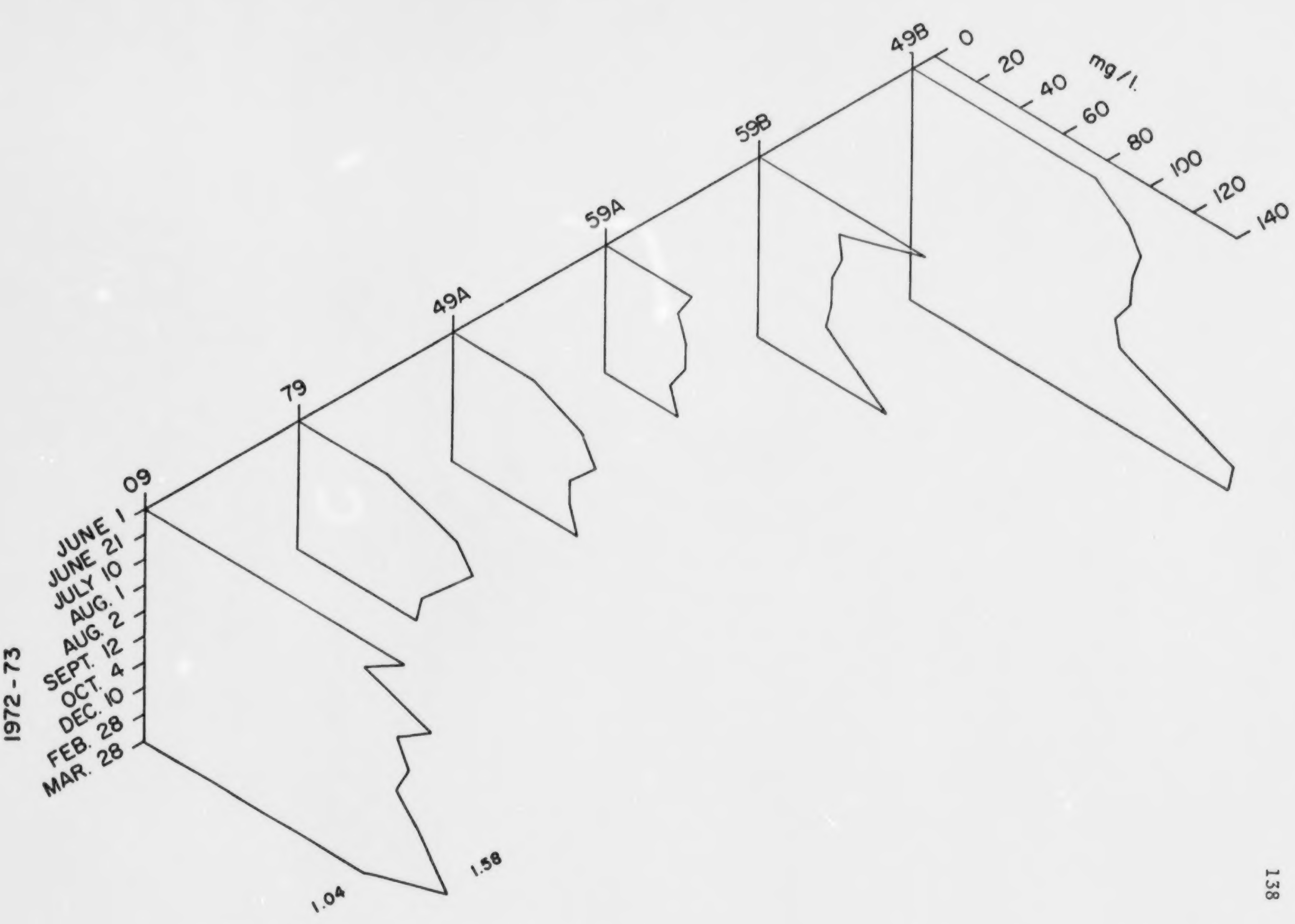


Figure 35 . Potassium, Southern Indian Lake.

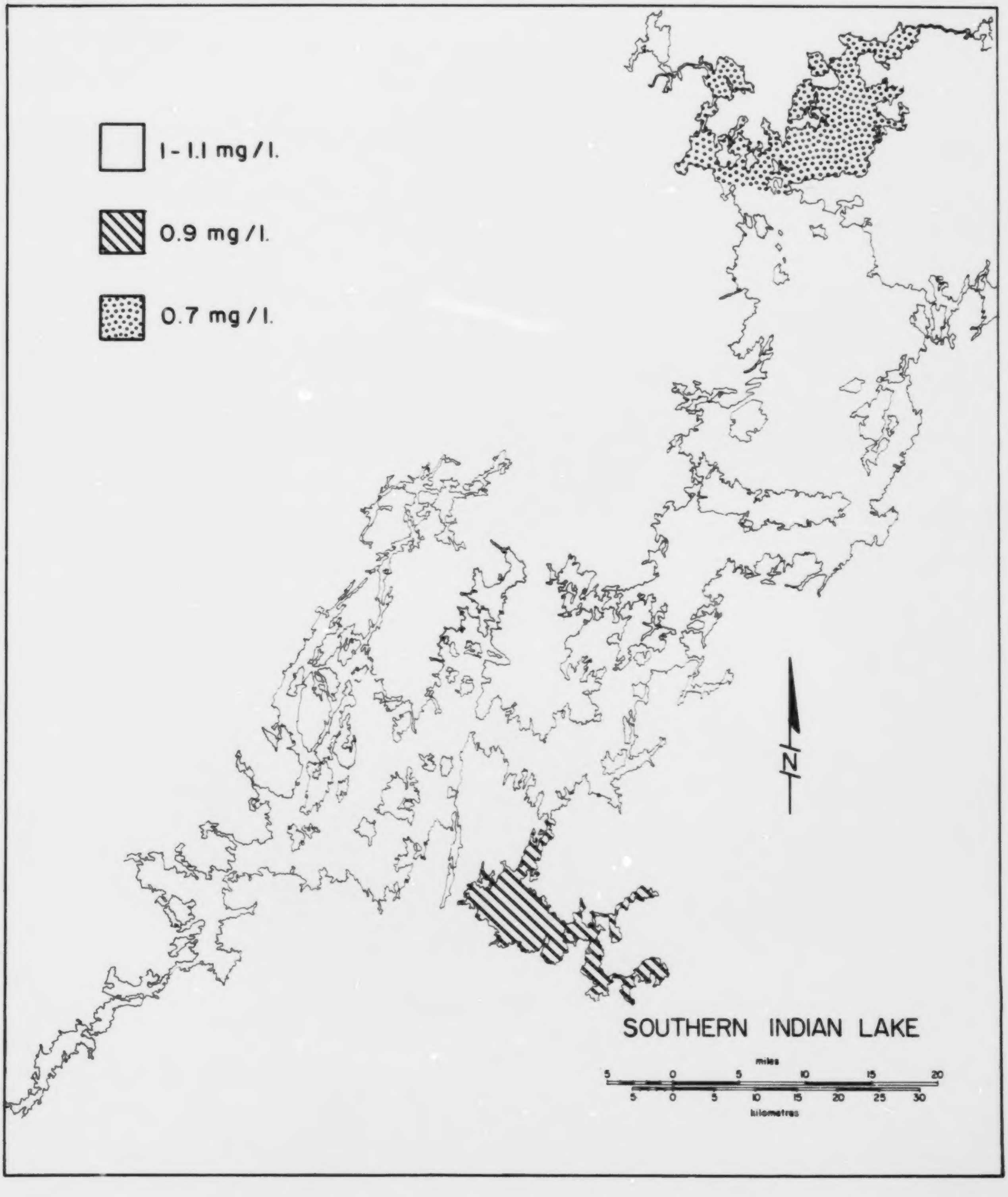

1 - 1.1 mg / l.
0.9 mg / l.
0.7 mg / l.
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

Figure 36 . Potassium, June-October 1972.

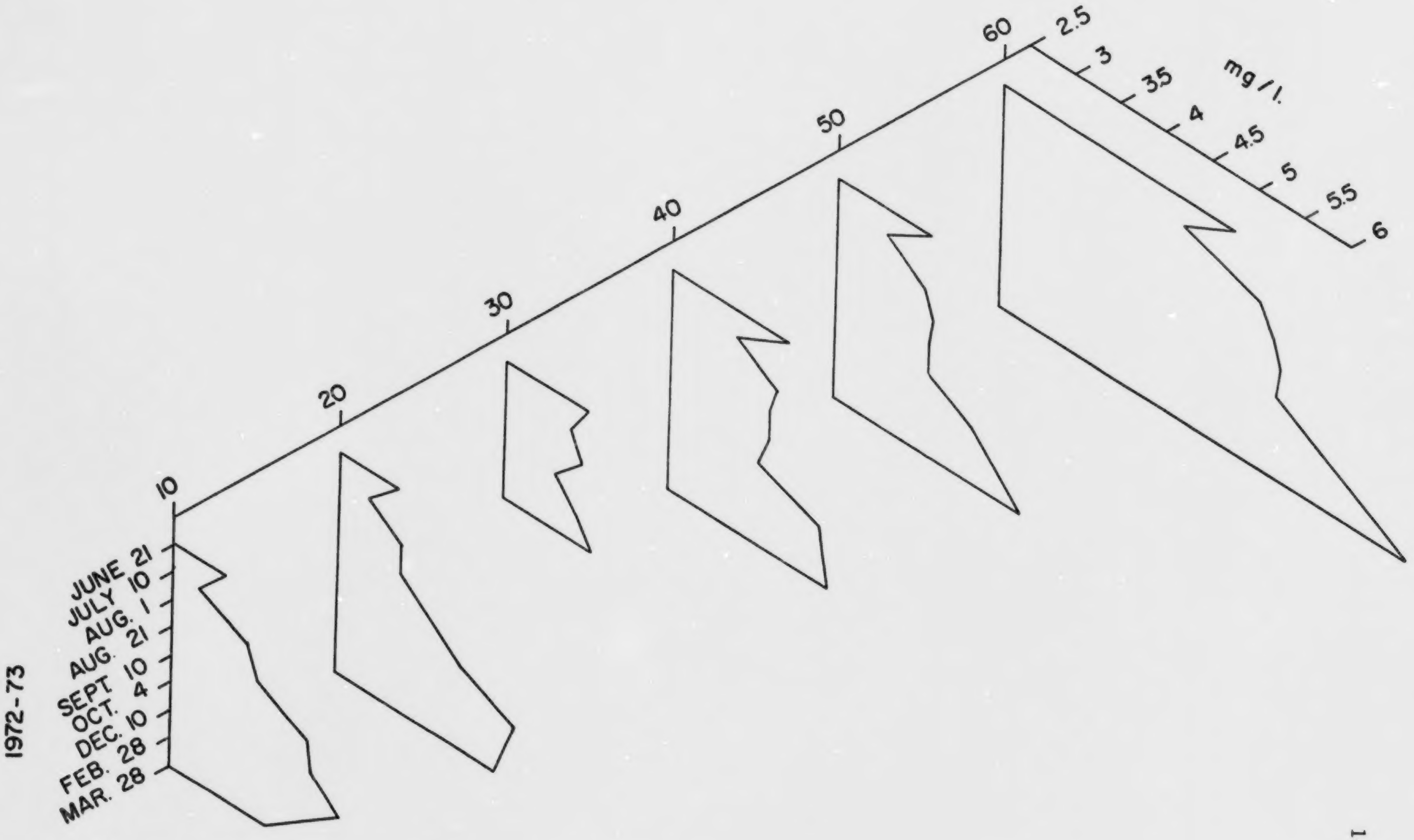
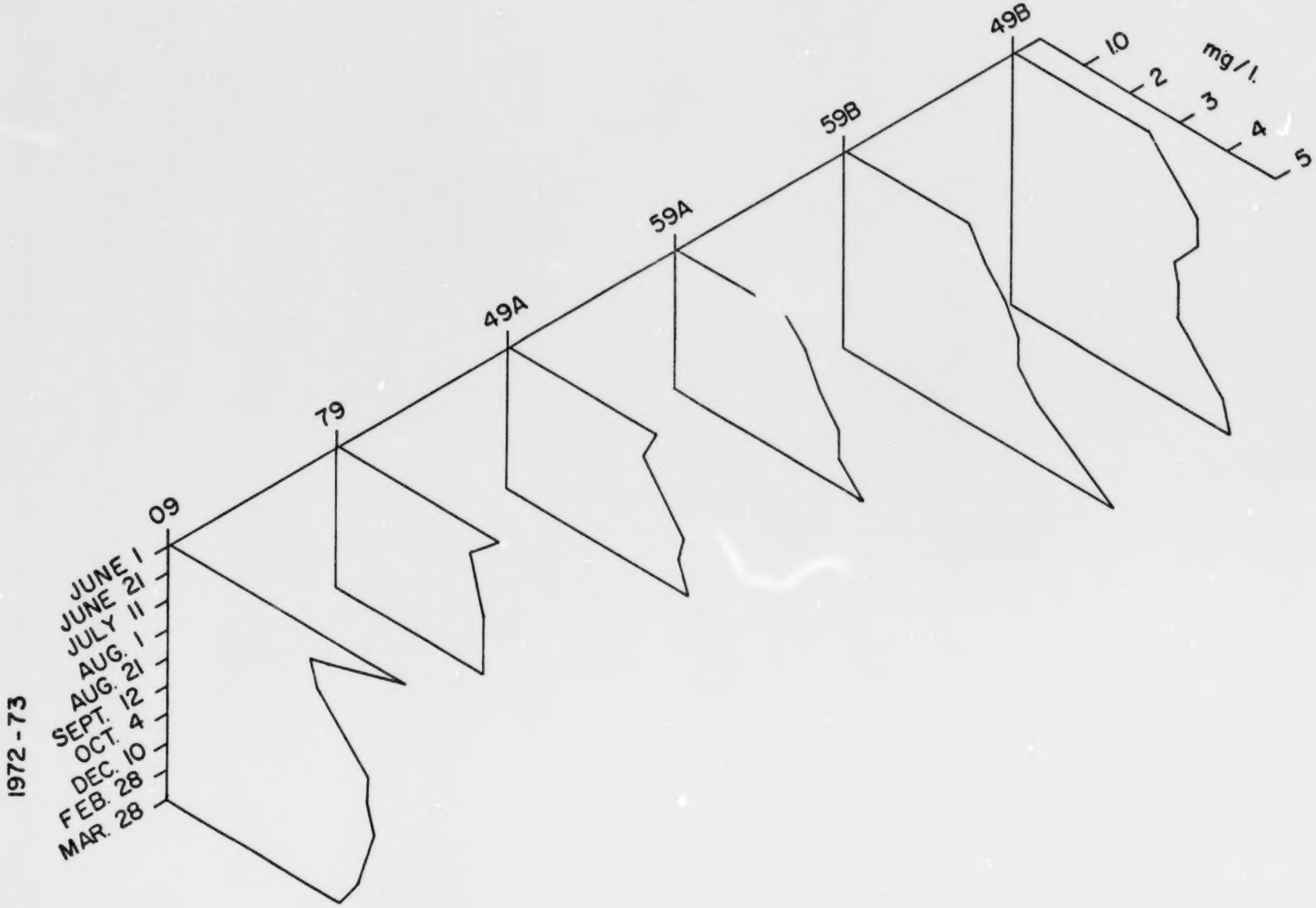


Figure 37 . Magnesium, Southern Indian Lake.


09
79
49A
59A
59B
49B
1.0
2
3
4
5
mg/l.
JUNE 1
JUNE 21
JULY 11
AUG. 1
AUG. 21
SEPT. 12
OCT. 4
DEC. 10
FEB. 28
MAR. 28
1972-73

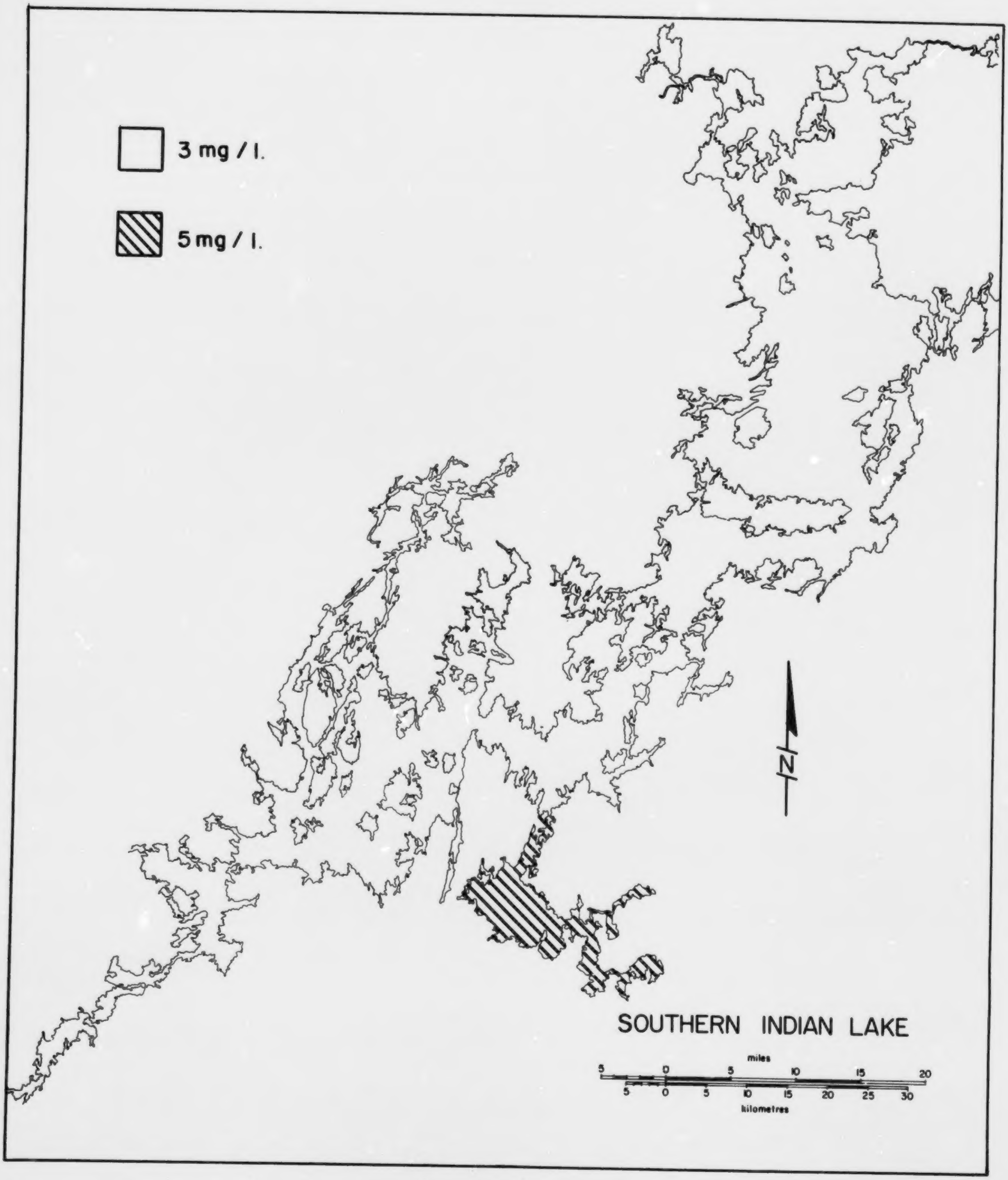
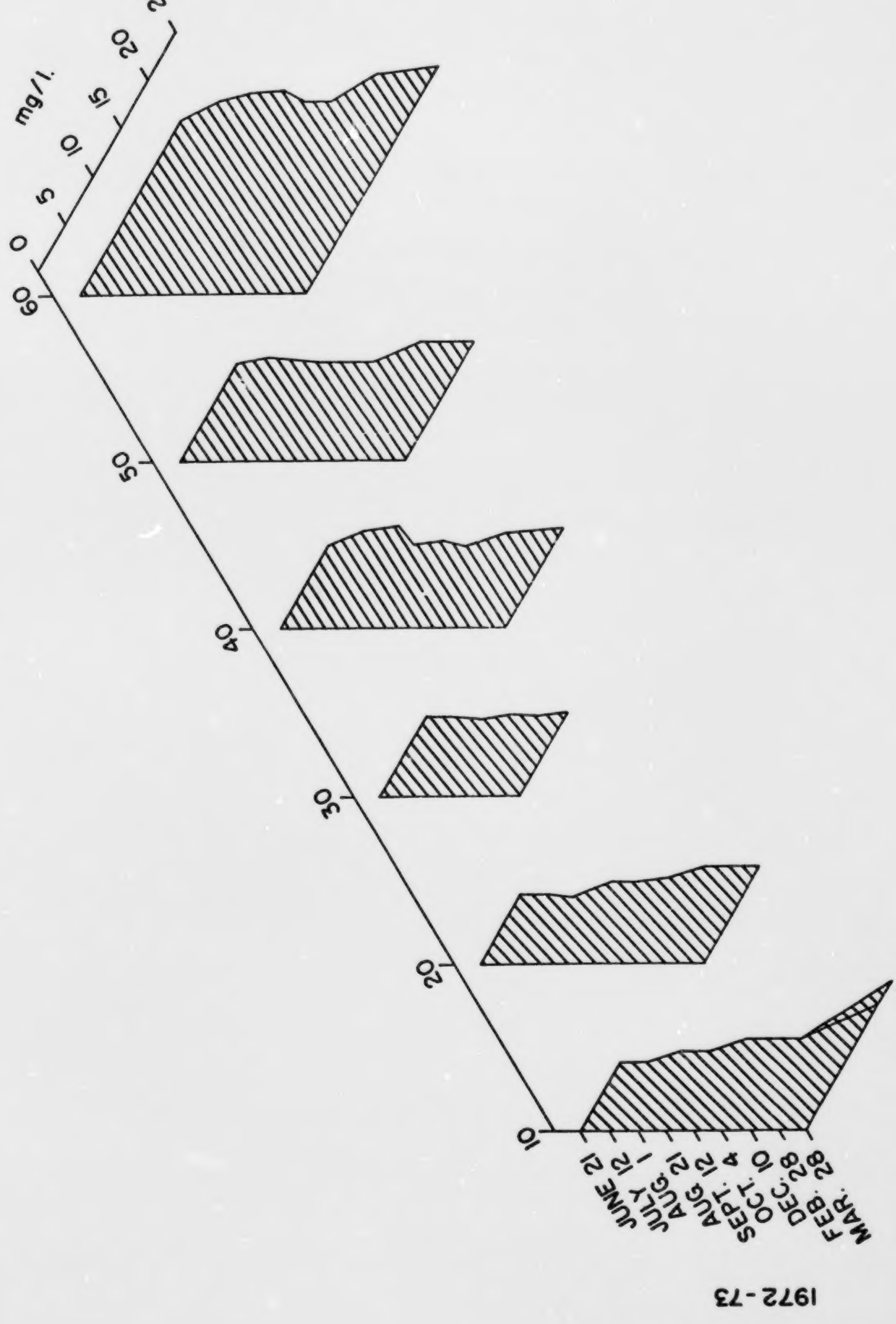
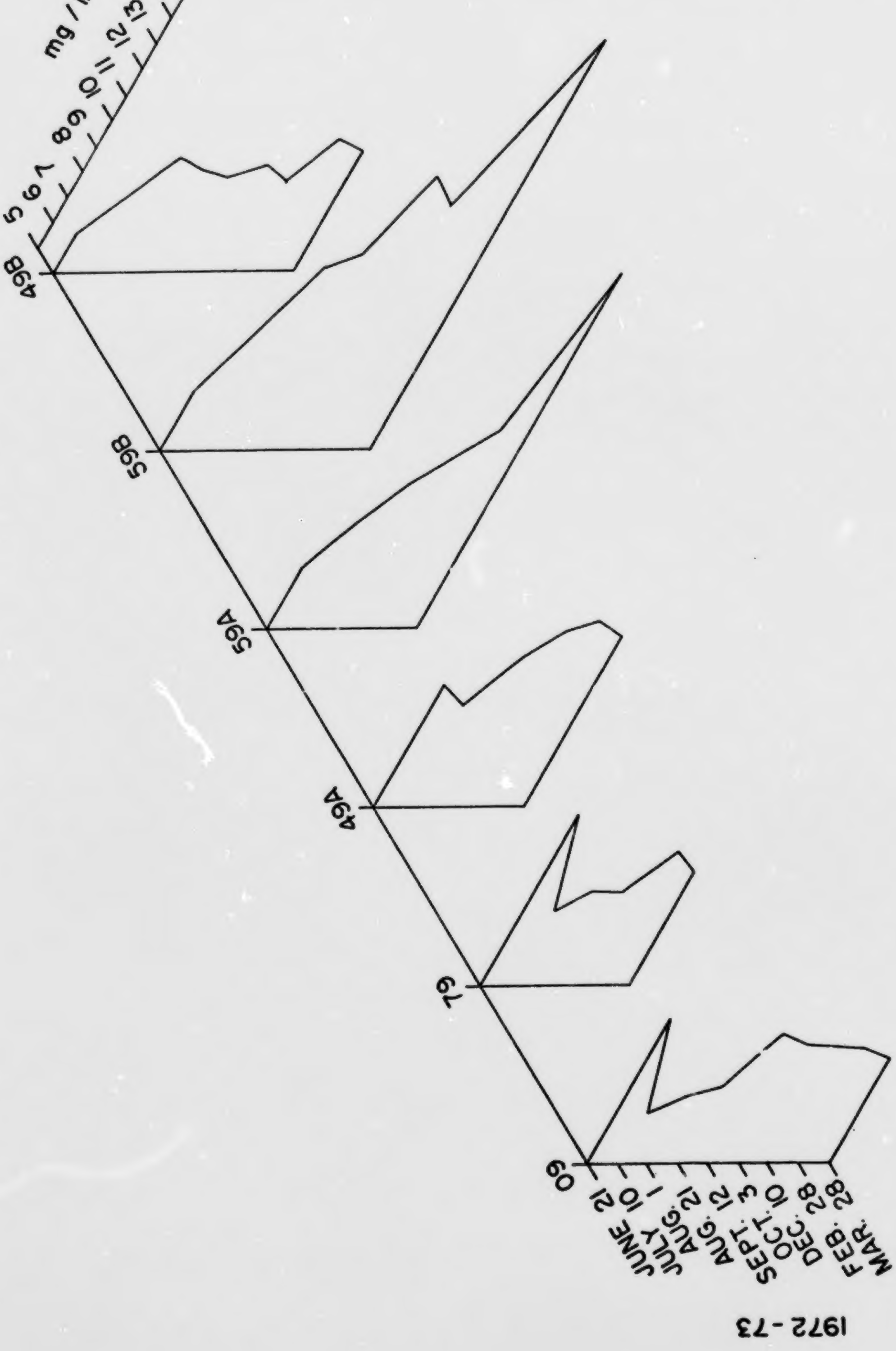

3 mg / l.
5 mg / l.
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres
N

Figure 39 . Magnesium, June-October 1972.


mg/l.
0
5
10
15
20
25
60
50
40
30
20
10
JUNE 21
JULY 12
AUG. 1
AUG. 21
SEPT. 12
OCT. 4
DEC. 10
FEB. 28
MAR. 28
1972-73


mg / l.
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
49B
59B
59A
49A
79
09
JUNE 21
JULY 10
JULY 1
AUG. 21
AUG. 12
SEPT. 3
OCT. 10
DEC. 28
FEB. 28
MAR.
1972-73

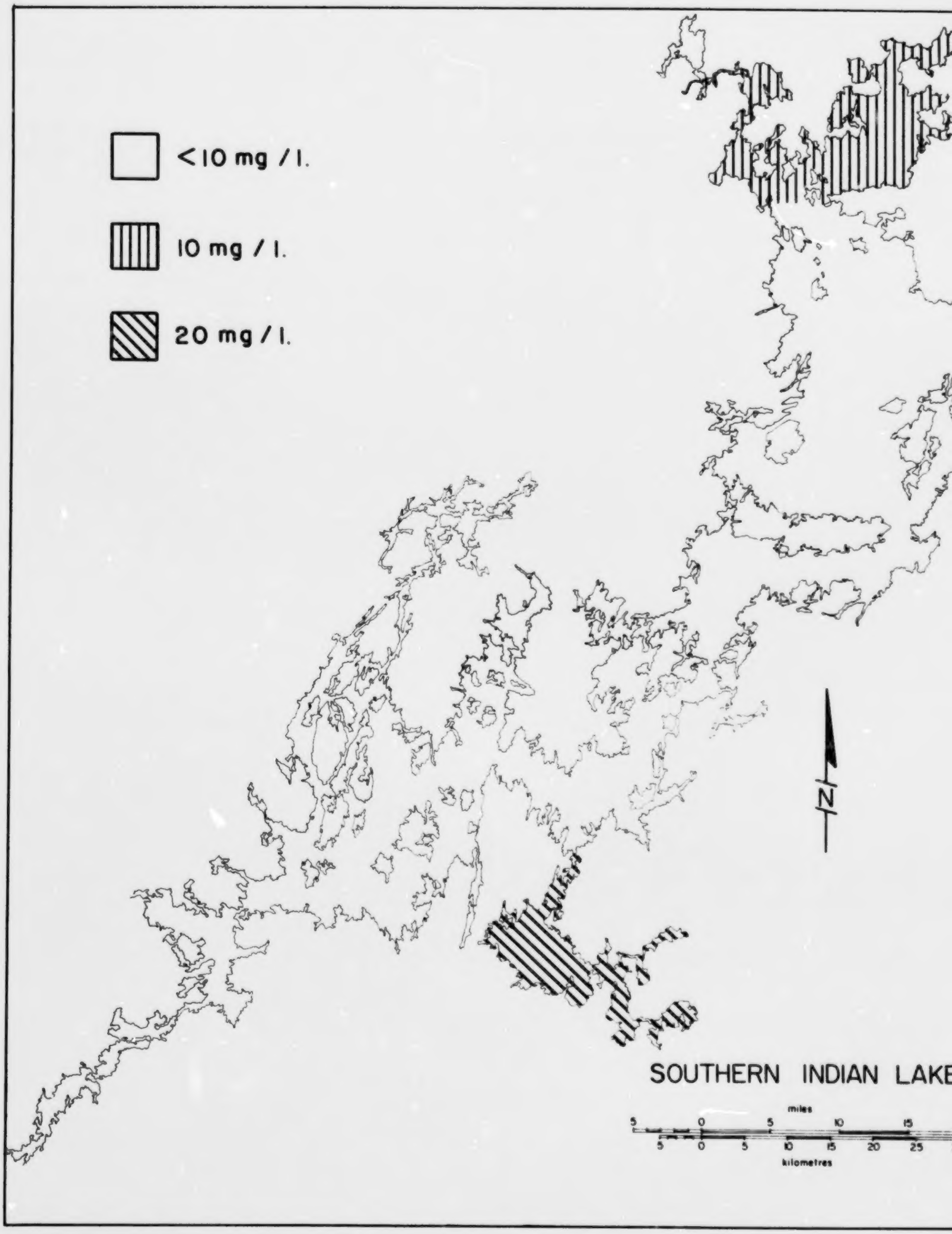

<10 mg / l.
10 mg / l.
20 mg / l.
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15
5 0 5 10 15 20 25
kilometres

Figure 42 . Calcium, June-October 1972.

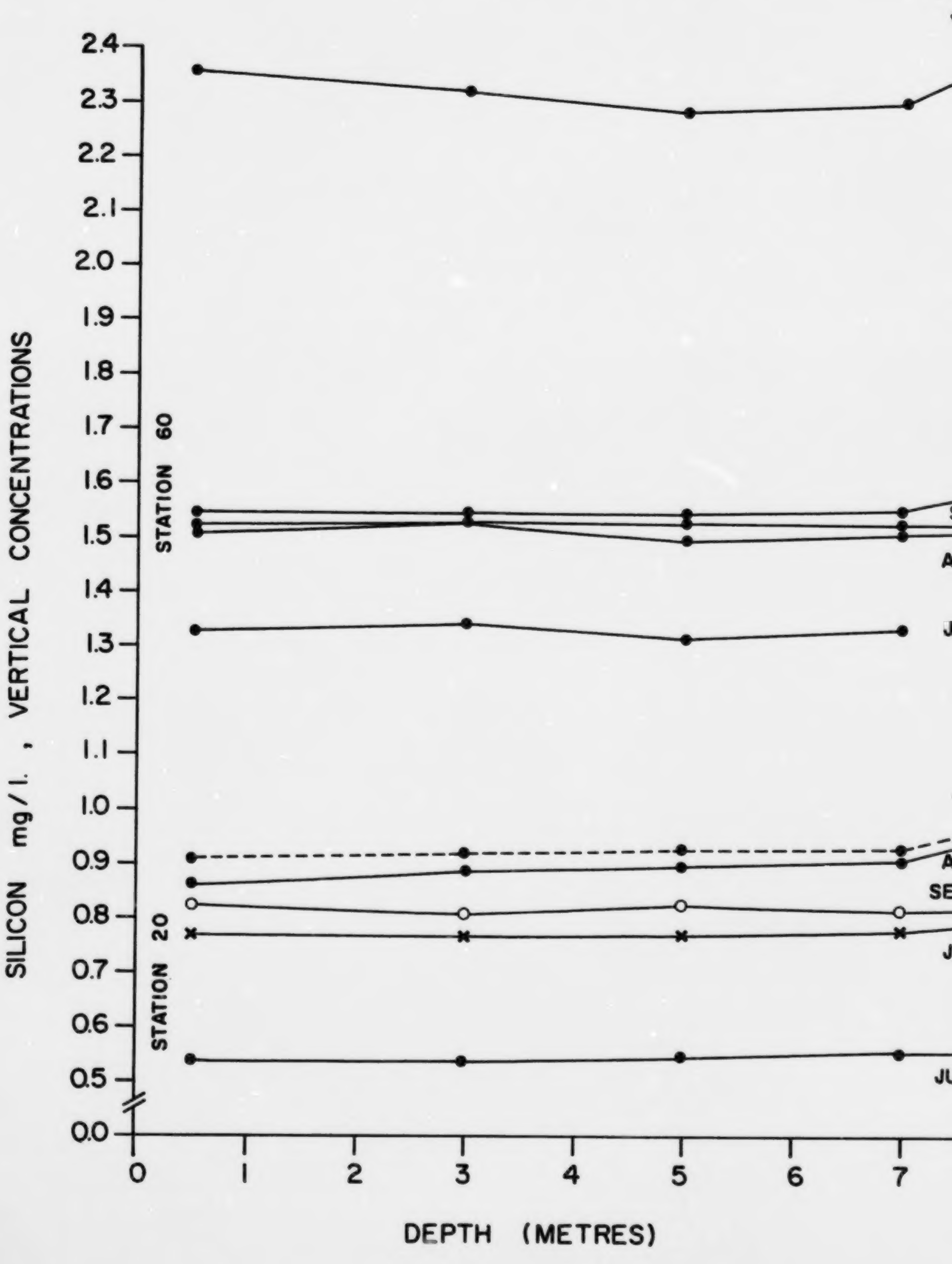
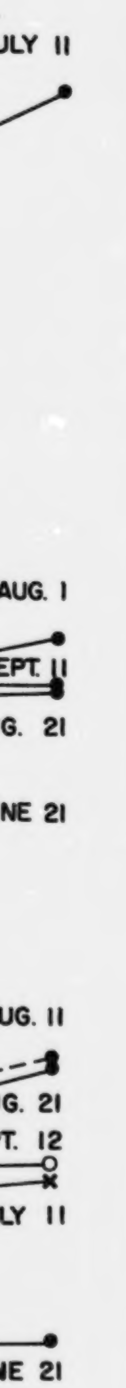


Figure 43 . Silicon, vertical concentrations at stations 20 and 60.



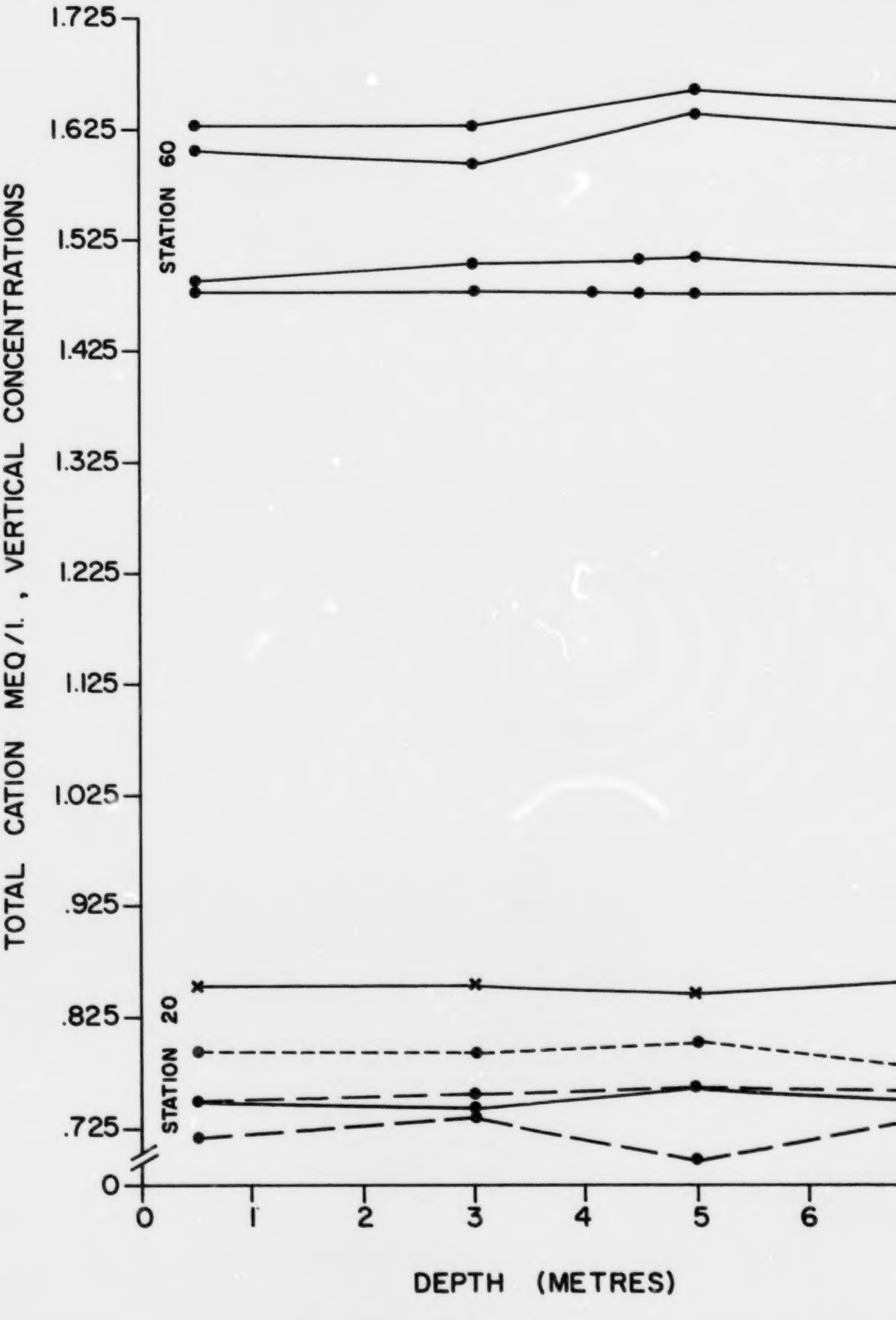


Figure 44 . Total cations, vertical gradient for stations 20 and 6

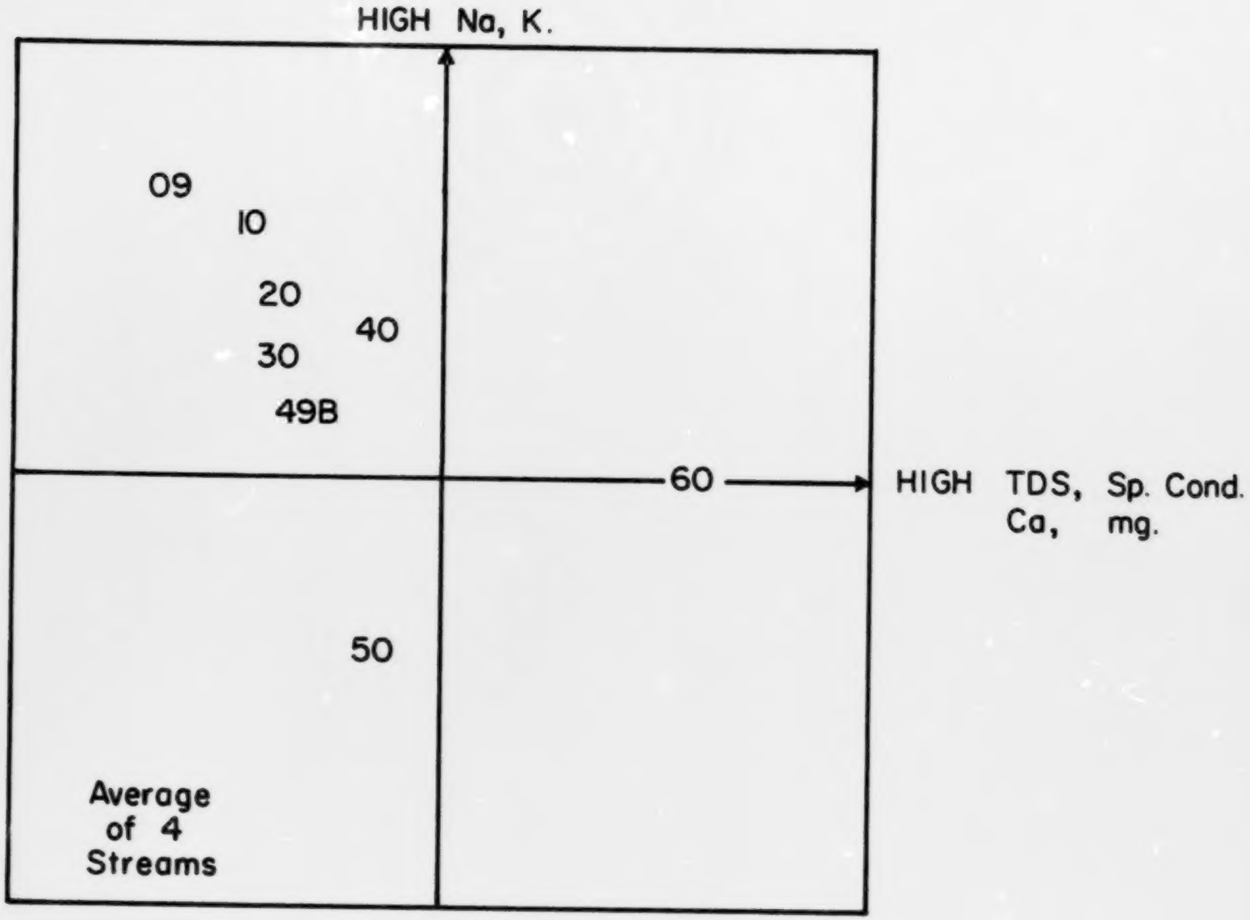
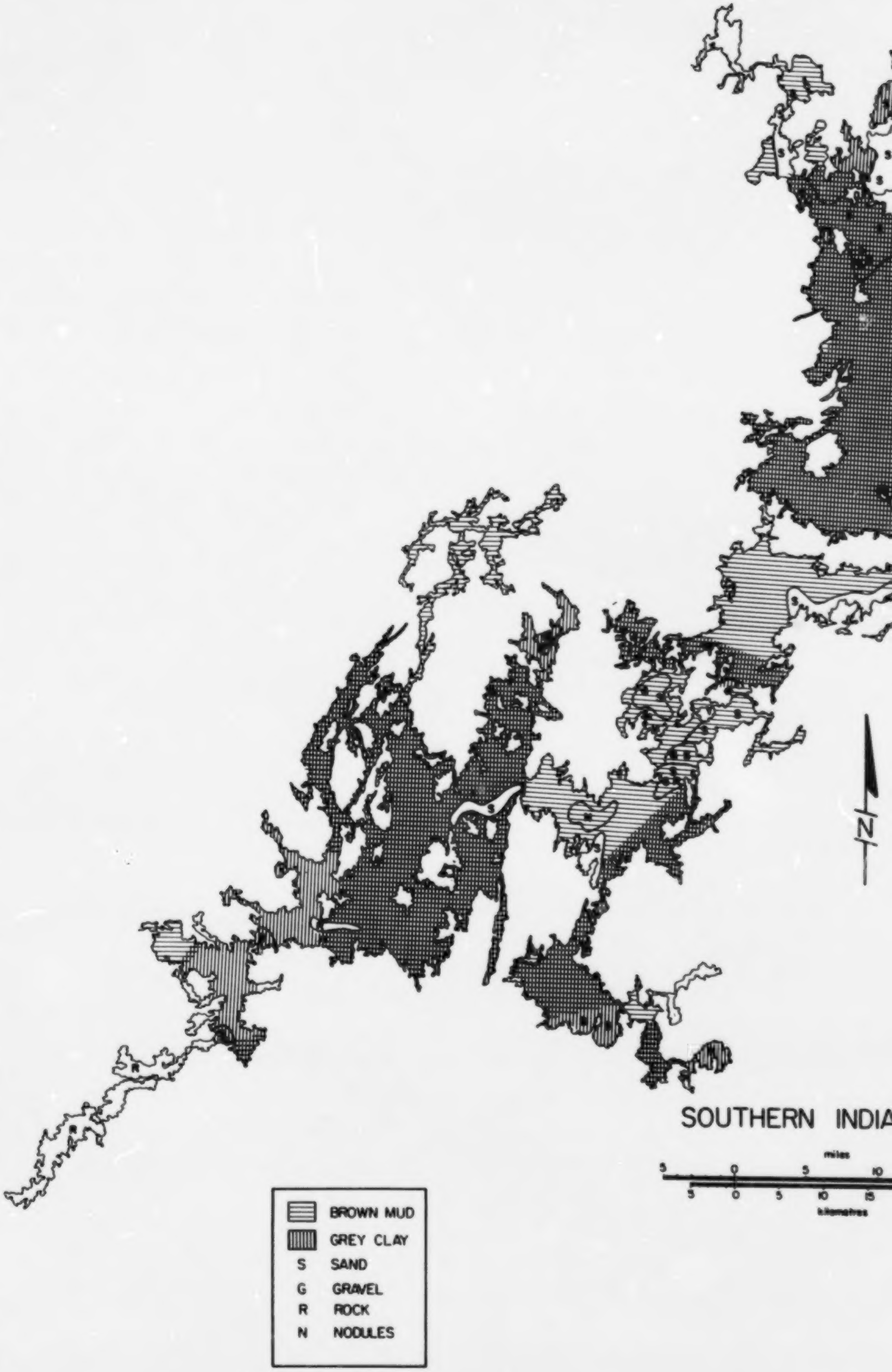

HIGH Na, K.
09
10
20
40
30
49B
60
HIGH TDS, Sp. Cond.
Ca, mg.
50
Average of 4 Streams

Figure 45. Comparison of some water components, main stations, Southern Indian Lake, 197


S
N
R
SOUTHERN INDIA
miles
5 0 5 10
5 0 5 10 15
kilometres
BROWN MUD
GREY CLAY
S SAND
G GRAVEL
R ROCK
N NODULES

APPENDIX III

Computed Breakdown of Total CO_2, Southern Indian Lake, 1972-73.

Table 1. Computed breakdown of total CO_2 from chemical analysis, Southern Indian Lake, 1972.

DATE	1 June						21 June					
STATION	09	79	49A	59A	59B	49B	09	79	49A	59A	59B	49B
DEPTH (m)	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Tot CO_2 µmoles	326	283	228	185	169	194	313	288	305	313	355	438
HCO_3 molesx10^{-4}	3.1	2.7	2.2	1.7	1.6	1.8	3.0	2.7	2.9	3.0	3.3	4.2
CO_3 molesx10^{-7}	5.8	4.5	3.5	2.6	2.4	2.9	6.5	4.7	4.6	4.6	5.3	7.5
CO_2+H_2CO_3 molesx10^{-5}	1.6	1.5	1.3	1.1	1.0	1.1	1.3	1.5	1.7	1.8	2.0	2.2
P_{CO_2}x10^{-4}	2.6	3.0	2.4	1.9	1.7	1.5	2.7	3.1	3.2	3.2	3.7	3.5

	21 June											
	10			20				30			40	
	0.5	7	B	0.5	5	7	B	0.5	7	B	0.5	7
Tot CO_2 moles	300	293	308	300	300	316	331	308	316	300	339	362
HCO_3 molesx10^{-4}	2.8	2.8	2.9	2.8	2.8	3.0	3.1	3.0	3.0	2.9	3.2	3.4
CO_3 molesx10^{-7}	4.7	4.5	4.6	4.6	4.5	4.7	4.9	5.9	5.9	5.6	6.1	6.2
CO_2+H_2CO_3 molesx10^{-5}	1.6	1.6	1.7	1.7	1.7	1.8	1.9	1.4	1.5	1.4	1.6	1.8
P_{CO_2}x10^{-4}	3.1	3.0	3.2	3.1	3.1	3.2	3.4	2.6	2.6	2.5	2.7	2.9

DATE	21 June, 1972							10 July, 1972					
STATION	50			60				09	79	49A	59A	59B	49B
DEPTH	0.5	7	B	0.5	3	5	7	0.5	0.5	0.5	0.5	0.5	0.5
CO_2	354	362	354	655	678	608	655	704	632	812	307	948	912
HCO_3	3.4	3.4	3.4	6.4	6.6	5.9	6.3	6.8	6.1	7.9	3.0	9.2	8.9
CO_3	6.3	6.3	6.2	21.9	22.1	19.7	21.0	16.6	19.2	24.6	7.3	28.9	32.2
$CO_2+H_2CO_3$	1.7	1.8	1.7	1.8	1.9	1.7	1.8	2.7	1.9	2.5	1.2	2.9	2.4
P_{CO_2}	2.9	2.9	2.8	3.6	3.7	3.3	3.5	6.3	4.5	5.8	2.7	6.8	5.1

	10 July, 1972											
	10			20						30		
	0.5	7	B	0.5	3	5	7	10	B	0.5	7	B
CO_2	637	653	729	628	670	628	645	645	653	704	670	670
HCO_3	6.2	6.3	6.8	6.0	6.4	6.0	6.1	6.2	6.3	6.8	6.4	6.1
CO_3	23.7	14.9	10.1	13.9	11.7	10.9	11.2	14.3	14.4	19.5	14.7	6.5
$CO_2+H_2CO_3$	1.6	2.6	4.5	2.6	3.4	3.2	3.3	2.6	2.7	2.3	2.8	5.6
P_{CO_2}	3.6	5.7	9.9	5.5	7.3	6.8	7.0	5.6	5.7	4.9	5.8	10.8

	40			50			60				
	0.5	7	B	0.5	5	B	0.5	3	5	7	B
CO_2	745	737	829	796	779	829	1374	1365	1424	1390	1491
HCO_3	7.2	7.2	8.0	7.7	7.6	8.0	13.4	13.3	13.9	13.6	14.5
CO_3	20.4	25.3	20.8	28.2	27.6	23.1	63.5	79.6	82.8	80.6	52.7
$CO_2+H_2CO_3$	2.5	2.0	2.9	2.1	2.0	2.7	2.8	2.2	2.3	2.3	3.9
P_{CO_2}	5.1	4.1	5.6	4.4	4.3	5.8	6.2	4.9	5.1	5.0	8.3

	1 August														
	09	79	49A	59A	59B	49B	10			20					
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7	B	0.5	3	5	7	10	B
CO_2	460	450	440	460	460	420	420	480	420	310	350	330	390	450	400
HCO_3	4.4	4.3	4.3	4.4	4.4	4.1	4.0	4.6	4.0	3.0	3.4	3.2	3.8	4.4	3.9
CO_3	10.5	10.0	19.7	10.1	12.6	14.4	9.3	13.5	9.3	8.8	7.8	7.3	22.2	20.2	11.2
CO_2+H_2CO_3	1.8	1.8	0.9	1.9	1.5	1.1	1.7	1.6	1.7	1.0	1.4	1.3	0.7	0.9	1.3
P_{CO_2}	4.1	3.9	2.0	4.0	3.2	2.3	3.7	3.3	3.7	2.2	3.1	2.9	1.4	2.0	2.8

	30			40		50			60				
	0.5	7	B	0.5	7	0.5	5	B	0.5	3	5	7	B
CO_2	420	350	350	320	350	500	390	490	760	640	770	780	620
HCO_3	4.0	3.4	3.4	3.1	3.4	4.8	3.7	4.7	7.4	6.3	7.5	7.6	6.1
CO_3	9.3	9.8	9.8	6.7	9.3	13.6	8.4	10.5	34.8	36.9	44.4	45	35.2
CO_2+H_2CO_3	1.7	1.2	1.2	1.4	1.2	1.7	1.6	2.1	1.6	1.1	1.3	1.3	1.0
P_{CO_2}	3.7	2.4	2.4	2.7	2.4	3.4	3.4	4.2	3.4	2.3	2.7	2.8	2.2

		21 August								
	70	09	79	49A	59A	59B	49B	10		
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.7	B
CO_2	315	510	410	580	530	600	400	470	530	510
HCO_3	3.1	4.9	4.0	5.6	5.2	5.8	3.9	4.5	5.1	5.0
CO_3	14.1	15.2	16.1	22.8	40.8	22.9	11.2	14.1	15.6	14.6
CO_2+H_2CO_3	0.7	1.6	1.0	1.4	0.7	1.5	1.3	1.5	1.7	1.6
P_{CO_2}	1.4	3.6	2.4	3.3	1.5	3.4	2.8	3.4	3.8	3.6

DATE											
STATION	20					30			40		
DEPTH	3	5	7	10	B	0.5	7	B	0.5	7	B
CO_2	450	480	430	460	460	460	500	460	490	500	460
HCO_3	4.4	4.6	4.2	4.4	4.4	4.4	4.8	4.4	4.7	4.8	4.4
CO_3	13.2	14.0	12.5	13.4	13.3	13.8	14.5	13.1	14.1	14.3	12.5
$CO_2+H_2CO_3$	1.4	1.5	1.4	1.5	1.5	1.4	1.6	1.5	1.6	1.6	1.5
P_{CO_2}	3.2	3.4	3.0	3.2	3.2	3.3	3.5	3.2	3.4	3.5	3.2

	50			60				70			
	0.5	5	B	0.5	0.3	5	B	5	10	20	B
CO_2	520	540	560	970	960	960	970	490	500	500	530
HCO_3	5.0	5.2	5.4	9.5	9.4	9.4	9.5	4.7	4.8	4.8	5.1
CO_3	15.5	15.3	15.6	45.5	45.1	45.1	57.5	14.5	14.7	14.0	14.8
$CO_2+H_2CO_3$	1.6	1.8	1.8	2.0	1.9	1.9	1.6	1.5	1.6	1.6	1.7
P_{CO_2}	3.7	3.8	3.9	4.4	4.3	4.3	3.5	3.5	3.5	3.5	3.7

	12 September								
	09	79	49A	59A	59B	49B	10		
	0.5	0.5	0.5	0.5	0.5	0.5	0.5	7	B
CO_2	918	700	890	1000	1040	780	860	860	860
HCO_3	8.8	6.8	8.6	10.0	10.1	7.5	8.3	8.3	8.3
CO_3	23.8	21.6	27.3	59.7	31.0	19.5	22.2	22.1	22.1
$CO_2+H_2CO_3$	3.2	2.0	2.6	1.5	3.1	2.8	3.0	3.0	3.0
P_{CO_2}	6.2	3.7	4.7	1.7	5.5	5.2	5.8	5.8	5.8

	20						30			40		
	0.5	3	5	7	10	B	0.5	7	B	0.5	7	B
CO_2	770	808	720	760	760	770	710	760	750	775	770	780
HCO_3	7.4	7.8	6.9	7.3	7.3	7.4	6.9	7.3	7.3	7.5	7.5	7.6
CO_3	19.8	20.8	18.5	19.5	19.5	19.8	23.0	19.3	18.7	31.5	24.5	24.8
$CO_2+H_2CO_3$	2.7	2.8	2.5	2.7	2.7	2.7	2.0	2.7	2.7	1.7	2.2	2.2
P_{CO_2}	5.2	5.5	4.9	5.1	5.1	5.2	3.8	5.1	5.1	3.3	4.1	4.2

	50			60				
	0.5	7	B	0.5	3	5	7	B
CO_2	890	880	820	1600	1500	1550	1460	1500
HCO_3	8.6	8.5	7.9	15.6	14.6	15.1	14.3	14.7
CO_3	27.3	21.3	19.8	63.8	59.3	61.3	72.9	74.9
$CO_2+H_2CO_3$	2.6	3.2	3.0	3.7	3.4	3.6	2.7	2.8
P_{CO_2}	4.7	5.8	5.4	6.8	6.4	6.6	5.0	5.1

	3 October									
	09	49B	10	20		30	40	50	60	
	0.5	0.5	0.5	0.5	B	0.5	0.5	0.5	0.5	B
CO_2	860	690	840	810	790	740	780	820	1420	1390
HCO_3	8.3	6.6	8.0	7.7	7.5	7.0	7.4	7.8	13.6	13.4
CO_3	23.7	14.9	14.3	13.9	13.5	12.6	13.4	13.8	30.9	38.4
$CO_2+H_2CO_3$	2.7	2.7	4.2	4.0	3.9	3.7	3.8	4.1	5.6	4.4
P_{CO_2}	4.4	4.4	6.7	6.4	6.3	5.9	6.2	6.5	9.1	7.1

	12 December									
	59B	10		20		40		50		60
	0.5	0.5	B	0.5	B	0.5	B	0.5	B	0.5
CO_2	440	250	260	270	270	280	250	280	270	460
HCO_3	4.2	2.4	2.3	2.6	2.5	2.6	2.4	2.6	2.6	4.5
CO_3	6.4	3.6	1.9	5.0	3.3	4.1	5.2	3.2	5.4	13.6
CO_2+H_2CO_3	2.4	1.4	2.6	1.2	1.8	1.6	1.0	1.9	1.1	1.3
PCO_2	3.3	1.9	3.8	1.6	2.6	2.1	1.6	2.6	1.7	1.8

Table 2 . Program for determination of various components of the carbonate equilibrium in a water sample from dissolved inorganic carbon, (after Garrels and Christ, 1965).

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1. $$[CO_2 + H_2CO_3] = \frac{(10^{-pH})^2 \text{ x } \Sigma CO_2}{(10^{-pH})^2 + 10^{-pH} \text{ x } Ka) + KaKb}$$

where $[CO_2 + H_2CO_3]$ = concentration of dissolved CO_2

Ka, Kb, Kc are activity products for H_2CO_3, HCO_3 and CO_2 respect

ΣCO_2 = dissolved inorganic carbon (μmoles/liter)

$$Ka = \frac{[H^+][HCO_3^-]}{[H_2CO_3]} = 10^{-(6.57 - (0.00926 \text{ x } T))}$$ where T =

sample temperature in °C at time of collection

$$Kb = \frac{[H^+][CO_3^{--}]}{[HCO_3^-]} = 10^{-(10.614 \mp (0.0117 \text{ x } T))}$$

2. $$[HCO_3^-] = \frac{(10^{-pH})^2 \text{ x } Ka \text{ x } \Sigma CO_2}{((10^{-pH})^2 + (10^{-pH} \text{ x } Ka) + (KaKb))}$$

3. $$[CO_3^{--}] = \frac{KaKb \text{ x } \Sigma CO_2}{((10^{-H})^2 + (10^{-pH} \text{ x } Ka) + (KaKb))}$$

4. $$P_{co_2} = \frac{[CO_2 + H_2CO_3]}{Kc}$$

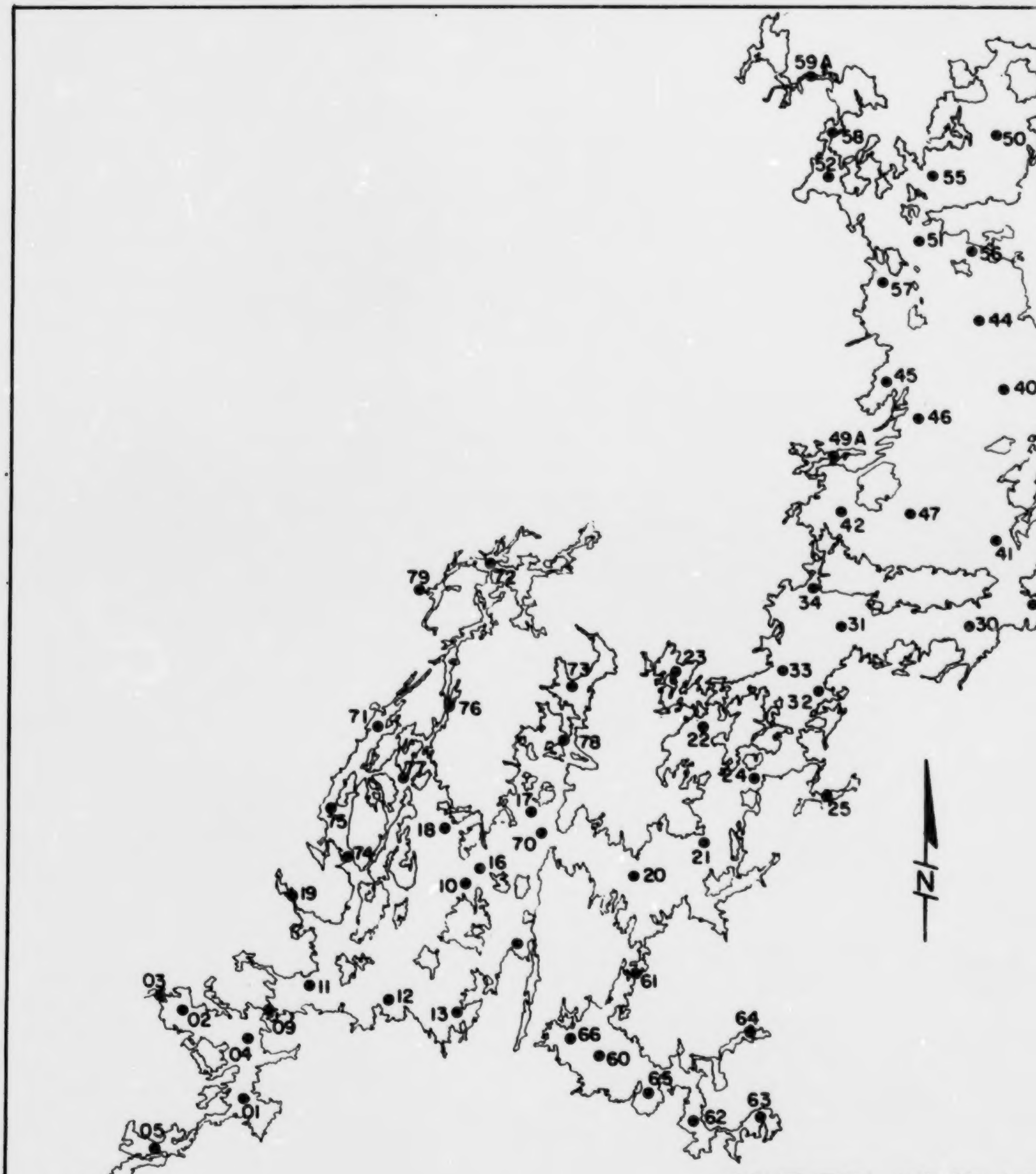
where P_{co_2} = partial pressure of CO_2

$$Kc = \frac{[CO_2 + H_2CO_3]}{P_{co_2}} = 10^{-(1.131 \text{ x } T)}$$

NOTE: Conductivity of Southern Indian Lake is less than 200 micromhos/cm.

APPENDIX IV

Chemical Analyses of Synoptic Station Water Samples, Southern Indian Lake, 1972.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CHEMISTRY STATIONS

Table 1. Synoptic chemical analysis (taken in conjunction with benthos). Southern Indian Lake. Depth 1/2 meter. 1972. For location of stations refer to Section 5 of the Fisheries Limnology Report.

DATE	July 1 and 2						July 30					July 16
STATION	01	02	03	04	05	06	10	11	16	17	18	19
Susp P (µg/1)	12	11	14	14	14	14	10	12	9	12	10	11
Chl a (g/1)	2.5	3.2	5.2	5.4	4.8	4.7	6.2	8.9	5.5	6.8	7.3	7.3
Secchi	1.2	1.0	1.0	1.4	1.2	1.0	1.3	1.0	1.5	1.5	1.8	1.2
TSS (mg/1)	4	2	< 1	1	5	5	2	1	< 1	< 1	< 1	2
TDS (mg/1)	49	38	39	46	42	55	42	53	47	45	44	64
Cond (µmoles/cm) @ 25°C	65	54	51	65	65	66	71	74	69	68	60	69
pH	7.8	7.6	7.6	7.7	7.8	7.7	7.8	7.8	7.8	8.1	7.9	-
Cl (mg/1)	1	1	1	1	1	1	1	< 1	1	1	1	1
SO_4 (mg/1)	4	3	3	4	4	4	4	5	4	4	5	3
Si (mg/1)	0.9	0.9	0.7	0.9	0.9	0.9	0.8	0.8	0.9	0.9	0.9	0.9
Na (mg/1)	2.2	1.5	1.5	2.2	2.5	2.2	2.4	2.5	2.4	2.4	2.3	2.4
K (mg/1)	2.9	2.3	2.3	2.9	2.9	3.1	3.3	3.5	3.2	3.2	3.2	3.2
Ca (mg/1)	6.8	6.3	5.7	6.7	6.6	6.9	7.7	8.0	9.6	7.7	7.9	7.3

	July 5-6						July 6-7					
	20	21	22	23	24	25	30	31	32	33	34	35
Susp P	7	11	8	18	9	12	7	7	7	8	8	24
Chl a	2.8	2.4	2.9	5.0	2.4	4.5	2.9	3.7	3.7	4.6	2.5	2.9
Secchi	1.9	2.0	2.5	0.7	2.0	1.5	2.0	2.0	2.1	2.3	1.2	1.5
TSS	2	2	3	8	3	3	2	10	1	< 1	9	5
TDS	48	33	26	55	53	60	49	50	50	52	17	53
Cond	70	70	72	88	71	77	76	72	75	75	77	77
pH	7.9	7.8	7.9	7.9	7.8	7.8	7.9	7.9	8.0	8.0	7.8	7.9
Cl	1	1	1	1	1	1	1	1	1	1	1	1
SO_4	3	3	4	4	3	3	3	3	3	3	3	3
Si	0.7	0.7	0.6	0.8	0.7	0.4	0.6	0.6	0.5	0.6	0.4	0.5
Na	2.4	2.4	2.5	2.4	2.4	1.1	2.6	2.5	2.5	2.5	2.7	2.7
K	1.0	1.0	1.0	0.9	1.0	0.5	1.1	1.0	1.0	1.0	1.1	1.1
Mg	3.3	3.0	3.2	3.7	3.2	3.2	3.1	3.4	3.1	3.3	3.5	2.8
Ca	8.0	7.1	7.6	10.4	7.5	10.3	8.4	7.7	7.8	9.9	8.0	8.4

	July 7-9								
	40	41	42	43	44	45	46	47	48
Susp P	6	8	17	6	5	11	5	6	8
Chl a	2.5	2.6	3.8	2.2	2.3	4.9	2.9	2.6	4.1
Secchi	3.4	2.4	3.5	3.8	3.1	2.9	2.9	3.3	2.7
TSS	2	4	3	1	2	1	< 1	< 1	1
TDS	45	50	55	61	66	59	62	43	56
Cond	83	76	87	85	86	86	83	81	79
pH	8.0	7.8	8.0	8.0	8.0	8.0	8.0	8.0	8.0
Cl	1	1	1	1	1	1	1	1	1
SO_4	4	3	4	4	4	4	4	4	4
Si	0.3	0.5	0.3	0.3	0.3	0.4	0.3	0.3	0.5
Na	2.7	2.7	3.0	2.8	2.9	2.7	2.9	2.8	2.9
K	1.0	1.0	1.1	1.0	1.0	1.0	1.0	1.1	1.1
Mg	3.7	3.5	4.1	3.9	3.9	3.8	3.8	3.6	3.6
Ca	9.2	8.0	9.2	9.5	9.7	9.7	9.3	8.3	8.5

	July 9 and 12								
	50	51	52	53	54	55	56	57	58
Susp P	7	7	11	10	7	8	6	6	13
Chl a	2.6	2.7	4.9	4.2	3.1	3.0	2.5	3.0	5.0
Secchi	2.8	2.7	1.1	1.0	3.0	2.5	3.2	2.3	0.8
TSS	2	< 1	2	< 1	< 1	< 1	1	< 1	4
TDS	59	55	67	66	56	61	53	55	78
Cond	81	85	67	78	85	81	88	80	67
pH	-	7.9	-	-	-	-	8.0	7.9	-
Cl	1	1	1	1	1	1	1	1	1
SO_4	3	4	4	3	3	3	4	4	4
Si	0.4	0.4	0.7	0.6	0.4	0.4	0.3	0.4	0.6
Na	1.7	2.4	1.1	1.6	2.2	1.9	2.9	2.0	1.2
K	0.6	0.9	0.4	0.4	0.6	0.6	1.0	0.7	0.4
Mg	3.5	3.4	2.9	3.2	3.7	3.5	4.0	3.5	3.0
Ca	10.5	9.9	9.6	11.2	10.8	9.9	9.9	9.8	9.8

	July 3-4							July 15-16							
	60	61	62	63	64	65	66	71	72	73	74	75	76	77	78
Susp P	9	10	19	51	11	13	8	8	9	7	11	11	10	9	9
Chl a	1.0	1.4	2.0	3.7	2.2	0.8	1.0	6.4	7.8	4.6	7.1	6.9	7.2	6.9	7.0
Secchi	1.7	1.2	0.4	0.1	0.9	0.6	1.6	2.5	1.8	2.1	1.5	2.0	1.8	2.0	2.2
TSS	2	4	16	65	4	8	1	1	< 1	< 1	1	1	1	< 1	1
TDS	64	79	95	179	77	96	86	84	66	75	64	68	59	74	69
Cond	134	111	130	132	119	135	134	68	78	84	65	70	69	69	76
pH	8.2	8.0	8.1	8.1	8.0	8.2	8.2	-	-	-	-	-	-	-	-
Cl	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
SO_4	4	4	3	3	3	4	4	4	3	4	4	4	4	4	4
Si	2.3	2.0	2.3	2.4	2.2	2.3	2.3	1.6	0.6	0.7	0.9	0.8	1.7	0.8	0.8
Na	2.2	2.4	1.7	1.5	1.6	2.2	2.2	1.5	1.1	3.0	2.3	2.4	1.3	2.3	2.7
K	0.8	0.9	0.8	1.0	0.6	0.8	0.9	0.8	0.4	1.1	1.0	1.0	0.7	0.9	1.1
Mg	5.3	4.7	5.1	4.4	4.9	5.0	5.2	3.0	3.2	4.0	2.9	3.1	3.0	3.2	3.5
Ca	19.3	14.9	21.4	20.4	16.7	20.2	19.9	8.6	11.2	9.1	7.0	7.4	9.1	7.4	8.2

Table 2. Synoptic chemical analysis (taken in conjunction with plankton). Southern Indian Lake August 26 - September 1, 1972. Depth 1/2 meter.

STATION		01	02	03	04	05	09
Susp P	(µg/1)	11	12	11	11	11	11
Chl a	(µg/1)	6.4	5.6	5.1	5.8	6.3	6.2
Secchi		2.0	1.3	1.5	1.9	2.0	2.0
TSS	(mg/1)	5	6	6	3	6	5
TDS	(mg/1)	98	25	33	36	70	36
Cond	(moles/cm	88	64	58	88	88	88
pH	@ 25°C)	7.6	7.7	7.5	7.5	7.7	7.5
Cl	(mg/1)	1	1	< 1	< 1	2	1
SO4	(mg/1)	13	4	4	7	4	4
Si	(mg/1)	0.9	0.9	0.9	0.9	0.9	0.9
Na	(mg/1)	3.0	1.7	1.4	3.0	3	2.9
K	(mg/1)	1.4	0.9	0.8	1.4	1.4	1.3
Mg	(mg/1)	4.5	3.0	2.8	4.4	4.4	4.3
Ca	(mg/1)	11.1	8.9	8.6	10.9	11.3	10.6

	10	10	11	12	13	14	15	16	17	18	19
Susp P	12	11	12	10	13	11	17	14	11	11	12
Chl a	5.1	5.3	5.5	4.1	6.3	7.0	5.5	6.9	5.2	6.8	5.1
Secchi	1.7	1.6	1.9	1.7	-	1.6	0.4	2.1	2.0	1.6	1.5
TSS	6	5	5	3	10	8	17	6	5	6	8
TDS	49	50	40	47	66	19	98	29	57	42	41
Cond	81	82	86	85	80	77	98	79	76	75	78
pH	7.7	7.6	7.5	7.6	7.6	7.7	7.7	7.6	7.6	7.7	7.6
Cl	1	1	1	1	1	1	1	1	1	1	1
SO_4	4	4	5	4	4	4	4	4	4	4	4
Si	0.9	0.9	0.9	0.9	0.9	0.9	1.4	0.8	0.9	0.9	0.9
Na	2.7	2.7	3.0	2.9	2.6	2.5	2.2	2.6	2.5	2.3	2.4
K	1.3	1.3	1.3	1.3	1.3	1.2	2.2	1.2	1.2	1.1	1.2
Mg	4.1	4.0	4.3	5.3	4.1	3.8	4.6	3.8	3.8	3.5	3.8
Ca	10.0	10.8	10.5	11.3	10.4	9.5	13.2	9.6	9.7	9.3	10.3

	20	21	22	23	24	25	30	31	32	33	34	35
Susp P	9	9	9	15	9	9	12	11	8	9	11	11
Chl a	5.7	7.8	7.6	5.6	7.7	3.8	9.6	6.8	9.3	5.7	5.5	8.4
Secchi	1.9	1.9	2.1	0.8	1.9	1.1	2.0	2.0	2.1	2.0	1.0	1.5
TSS	7	5	2	12	5	5	7	4	3	4	5	8
TDS	13	64	25	40	50	51	27	62	24	46	53	17
Cond	75	74	71	95	72	106	71	93	72	72	75	72
pH	7.4	7.6	7.3	7.6	7.3	7.7	7.4	8.3	7.4	7.5	7.5	7.7
Cl	1	1	1	1	1	1	< 1	1	1	1	1	1
SO_4	4	5	4	4	4	4	4	4	4	4	4	4
Si	0.9	0.8	0.9	0.8	0.8	0.6	0.8	0.9	0.8	0.9	0.8	0.8
Na	2.4	2.5	2.3	2.3	2.3	1.2	2.2	2.3	2.3	2.2	2.3	2.3
K	1.1	1.1	1.2	1.1	1.1	0.5	1.0	1.1	1.0	1.0	1.1	1.1
Mg	3.5	3.6	3.6	4.6	3.6	5.0	3.4	3.5	3.6	3.4	3.6	3.5
Ca	8.7	8.9	8.5	13.4	8.9	18.3	9.0	8.6	9.3	8.6	9.1	9.0

	40	41	42	43	44	45	45A	46	47	48
Susp P	12	11	10	12	9	10	11	8	8	12
Chl a	8.8	8.0	6.3	8.8	6.8	5.4	4.6	4.3	7.2	8.4
Secchi	3.0	2.3	2.9	2.8	3.0	2.4	1.5	2.5	2.8	1.9
TSS	4	7	4	4	6	3	5	4	5	7
TDS	85	53	79	77	83	55	20	18	43	28
Cond.	76	76	80	75	81	83	82	77	80	74
pH	7.6	7.4	7.7	7.5	7.5	7.3	7.3	7.4	7.4	7.6
Cl	1	1	1	< 1	1	1	1	1	1	1
SO_4	4	4	4	< 1	4	4	4	4	3	4
Si	0.5	0.6	0.6	0.6	0.4	0.7	0.5	0.6	0.5	1.0
Na	2.3	2.5	2.5	2.4	2.4	2.4	2.5	2.4	2.5	2.3

	50	51	52	53	54	55	56	57	58
Susp P	11	7	10	11	8	8	9	7	10
Chl a	5.1	4.5	6.4	2.5	4.3	4.8	6.1	4.7	4.3
Secchi	2.8	2.5	1.4	1.1	2.8	2.7	2.0	2.5	0.9
TSS	4	4	5	7	4	19	4	2	7
TDS	88	90	55	90	81	24	65	-	62
Cond	84	81	78	86	86	82	81	81	78
pH	7.5	7.5	7.4	7.5	7.7	7.8	7.7	7.4	7.4
Cl	1	1	1	1	1	1	1	1	1
SO_4	4	4	4	4	4	4	4	4	4
Si	0.5	0.5	0.8	0.6	0.6	0.6	0.5	0.5	0.5
Na	1.7	2.2	1.1	0.8	1.7	1.8	2.2	2.2	1.1
K	0.7	1.0	0.4	0.4	0.7	0.7	1.0	1.0	0.4
Mg	4.5	3.9	3.6	4.0	4.0	3.8	3.9	3.9	3.7
Ca	13.4	10.5	12.4	14.4	12.6	11.4	10.6	10.5	12.2

	60	61	62	65	66	73	74	75	77	78
Susp P	6	10	20	29	6	9	13	11	10	12
Chl a	3.0	3.4	3.4	3.5	2.7	4.6	6.0	6.3	5.0	4.7
Secchi	1.5	1.0	0.5	0.2	1.3	2.6	1.8	2.0	2.0	2.1
TSS	4	5	20	36	5	4	5	5	3	5
TDS	64	68	75	109	65	28	47	34	30	31
Cond	132	128	150	145	136	84	81	78	74	74
pH	8.0	8.0	8.1	8.0	8.0	7.7	7.8	7.6	7.6	7.5
Cl	< 1	1	< 1	< 1	1	< 1	1	1	< 1	1
SO_4	4	4	4	4	4	4	4	4	4	4
Si	1.6	1.5	1.6	1.7	1.5	0.9	0.9	1.0	1.2	1.0
Na	2.1	2.1	1.8	2.2	2.0	2.6	2.7	2.4	2.2	2.4
K	1.0	1.1	1.0	1.1	1.0	1.2	1.3	1.1	1.1	1.2
Mg	5.1	5.5	6.0	6.0	5.8	4.1	3.9	3.6	3.5	3.7
Ca	21.0	20.4	24.8	23.4	21.1	10.8	10.1	9.8	9.6	9.5

APPENDIX V

Observed Temperatures and Oxygen. Southern Indian Lake 1972-1973.

Table 1. Seasonal variation in temperature and oxygen between main stations on Southern Indian Lake. (Abbreviations: T, temperature °C; O_2, oxygen ppm; %, percent O_2 saturation; m, meter; B, bottom)

DATE	1972		31 May				20 June					
STATION	09	79	49A	59A	59B	49B	09	79	49A	59A	59B	49B
PARAMETER	T	T	T	T	T	T	T	T	T	T	T	T
0.5 m	7.1	12	10.1	8.1	8.1	1.5	12.5	13	10	8.5	9.8	5.5
3 m	-	12	10.1	8.1	8.1	-	12.5	12	10	8.5	-	5.5
3 m	-	12	10.1	8.1	8.1	-	12.5	12	10	8.5	-	5.5
5 m	-	-	-	8.1	-	-	12.5	-	10	-	-	5.2
7 m	-	-	-	-	-	-	12.5	-	10	-	-	5.2
10 m	-	-	-	-	-	-	12.5	-	-	-	-	5.2
B + 1 m	-	12	10.1	8.1	8.1	-	-	11	-	8.5	9.8	5.2

			21 June				July 10					
	10	20	30	40	50	60	09			79		
	T	T	T	T	T	T	T	O_2	%	T	O_2	%
0.5	11	10	9.5	7.5	7	12.5	17.5	9.0	96	18.1	8.9	96
3	10.7	9.8	9.5	7.0	7	12	-	-	-	-	-	-
5	10.7	9.8	9.0	6.9	6.9	11.9	17.1	9.0	96	18	8.9	96
7	10.5	9.5	9.0	6.0	6.5	11.5						
10	10.2	-	9.0	-	6.5	11.2						
B + 1	9.8	9.5	9.0	6.0	6.5	11	-	-	-	-	-	-

	49A			59A			59B			49B		
	T	O_2	%	T	O_2	%	T	O_2	%	T	O_2	%
0.5	18	8.9	96	18	8.3	89	18.2	8.9	97	15.0	10.6	108
3	18	9.1	98	18	8.3	90	-	-	-	-	-	-
5	-	-	-	-	-	-	-	-	-	15	10.8	110
B + 1	18	9.1	98	18	8.3	90	18.2	8.9	97	15	10.8	110

DATE STATION PARAMETER	10 T	0_2	%	20 T	0_2	%	July 11, 1972 30 T	0_2	%	40 T	0_2	%
0.5	15.8	9.5	97	15.2	9.6	97	14.8	9.7	98	14.3	10.1	97
3	-	-	-	15.2	9.5	96	14.8	9.7	98	-	-	-
5	-	-	-	15.2	9.5	96	14.8	9.7	98	-	-	-
7	15.2	9.4	94	15.2	9.5	96	14.8	9.7	98	14	10.3	103
10	15	9.1	91	15.2	9.5	96	-	-	-	-	-	-
B + 1	14.9	7.9	79	15.1	9.3	94	12	8.5	81	11.2	10.8	100
	60 T	0_2	%									
0.5	16.2	9.6	99									
3	16.2	9.6	99									
5	16.1	9.6	99									
7	16	9.5	98									
10	-	-	-									
B + 1	15	9	91									
	July 30, 1972 09 T	0_2	%	79 T	0_2	%	49A T	0_2	%	59A T	0_2	%
0.5	16.4	9.6	99	15.2	9.4	95	15.1	9.5	96	14.8	9.2	94
2	-	-	-	-	-	-	-	-	-	14.8	9.2	94
	59B T	0_2	%	49B T	0_2	%						
0.5	14.2	9.4	94	14	10.6	105						
2	14.2	9.4	94	-	-	-						

DATE	July 31, 1972											
STATION	10			20			30			40		
PARAMETERS	T	O_2	%	T	O_2	%	T	O_2	%	T	O_2	%
0.5	15.4	9.5	96	15.4	9.5	95	15.2	9.5	96	13.2	10.1	98
3	-	-	-	15.3	9.3	94	-	-	-	-	-	-
5	-	-	-	15.3	9.3	94	-	-	-	-	-	-
7	15.3	9.3	94	15.3	9.3	94	15.0	9.5	96	13.1	10	98
10	-	-	-	15.2	9.3	94	-	-	-	-	-	-
B + 1	15.3	9.3	94	15.1	9.1	92	15	9.5	96	13.1	10	98

	50			60			70		
	T	O_2	%	T	O_2	%	T	O_2	%
0.5	14.1	9.8	98	15.9	9.5	99	15	9.5	96
3	14.1	9.8	98	15.8	9.5	99	-	-	-
5	14.1	9.8	98	15.8	9.5	99	-	-	-
7	-	-	-	15.8	9.6	99	-	-	-
10	-	-	-	-	-	-	-	-	-
B + 1	14	9.6	96	15.2	9.6	97	-	-	-

	21 August, 1973											
	09			79			49A			59B		
	T	O_2	%	T	O_2	%	T	O_2	%	T	O_2	%
0.5	17.3	9.4	99	18.9	8.9	98	18.8	9.4	103	17.9	9.4	101
2	17.3	9.4	18.6	18.6	9	96	-	-	-	-	-	-

	59A			49B		
	T	O_2	%	T	O_2	%
0.5	17.8	8.8	96	15.1	10.4	106
2	-	-	-	-	-	-

DATE STATION PARAMETERS	10 T	O_2	%	20 T	O_2	%	30 T	O_2	%	40 T	O_2	%
0.5	17.6	9.6	101	17.6	9.6	101	17.5	9.6	103	16.1	9.6	99
3	17	9.6	100	16.9	100	16.9	9.5	100	-	-	-	-
5	-	-	-	16.5	9.3	97	-	-	-	-	-	-
7	16.5	9.1	95	16.5	9.3	97	16.3	9.4	98	16	9.4	98
10	16.3	9	93	16.5	9.3	97	-	-	-	-	-	-
15	-	-	-	-	-	-	16.1	9.2	95	15	9.3	94
B + 1	16	7.5	78	16.4	8.9	92	15.7	8.1	85	14	8.0	80

	50 T	O_2	%	60 T	O_2	%	70 T	O_2	%
0.5	17.4	9.2	98	16.8	9.4	99	18.1	9.7	104
3	-	-	-	16.8	9.4	99	17.1	9.6	101
5	15.6	9.3	96	16.8	9.4	99	16.8	9.3	99
7	-	-	-	-	-	-	-	-	-
10	-	-	-	-	-	-	16.3	9.1	94
15	-	-	-	-	-	-	15.1	8.3	84
B + 1	15	9.1	92	16.8	9.3	99	15	7.6	77

September 11, 1972

	09 T	O_2	%	79 T	O_2	%	49A T	O_2	%	59A T	O_2	%
0.5	12.3	10.2	98	10	10.9	99	9.8	11.2	102	8.5	11	96

	59B T	O_2	%	49B T	O_2	%
0.5	8.8	10.9	96	11	11	102

DATE STATION PARAMETERS	10 T	O_2	%	20 T	O_2	%	30 T	O_2	%	40 T	O_2	%
0.5	12.1	10.4	99	12	9.7	92	11.8	10	96	11.5	10.2	96
3	-	-	-	12	9.9	94	-	-	-	-	-	-
5	-	-	-	12	9.8	93	11.6	10	94	-	-	-
7	12.0	10.4	99	12	9.8	93	-	-	-	11.2	10.2	95
10	12.0	10.4	99	12	9.8	93	-	-	-	-	-	-
B + 1	12.0	10.4	99	12	9.8	93	10.5	9.9	91	11.2	10.1	94

	50 T	O_2	%	60 T	O_2	%	October 3, 1972 09 T	49B T	10 T	20 T	30 T	40 T	50 T	60 T
0.5	9.8	10.9	99	10.8	11.2	104	6.0	5.7	5.8	6.0	5.8	6.3	5.3	6.0
3	-	-	-	10.5	11.8	108								
5	9.8	11.1	100	10.5	11.8	108								
7	-	-	-	10.5	11.2	103								
10	-	-	-	-	-	-								
B + 1	9.8	11.1	100	10.5	11.2	103	-	-	5.7	5.6	5.2	-	5.2	5.8

	December 10, 1972 59B T	10 T	20 T	30 T	40 T	50 T	60 T	09 T	O_2	%	49B T	O_2	%
0.5	0	0	0	0	0	0	0	0	14	97	0	14.1	98
1	-	0.3	0.3	-	-	0.5	1.0	-	-	-	-	-	-
2	-	-	-	0.5	-	-	2.0	-	-	-	-	-	-
3	-	-	-	-	-	-	-	-	-	-	-	-	-
5	-	-	0.5	-	0.5	-	3.0	-	-	-	-	-	-
8	-	-	-	-	1.0	-	3.5	-	-	-	-	-	-
15	-	0.5	-	-	-	-	-	-	-	-	-	-	-
18	-	-	-	-	0.3	-	-	-	-	-	-	-	-
B + 1	-	2.0	2.5	2.5	4.0	3.0	4.0	-	-	-	-	-	-

February 28, 1973

	60		
	T	O_2	%
0.5	0	15.5	108
1	1	-	-
2	-	-	-
3	2.8	-	-
5	-	-	-
8	3.8	-	-
15	-	-	-
18	-	-	-
B + 1	4	-	-

March 28, 1973

	09			49B			10			20		
	T	O_2	%	T	O_2	%	T	O_2	%	T	O_2	%
0.5	0	14.7	102	0	13.0	90	0.25	13.1	92	0.25	15.6	109
1	-	-	-	-	-	-	0.25	-	-	0.3	-	-
3	-	-	-	-	-	-	0.25	-	-	0.35	-	-
5	-	-	-	-	-	-	0.25	-	-	0.5	-	-
7	-	-	-	-	-	-	0.25	-	-	0.51	-	-
16	-	-	-	-	-	-	0.52	-	-	-	-	-
B + 1	-	-	-	-	-	-	2.1	-	-	2.5	13.1	97

	40			50			60		
	T	O_2	%	T	O_2	%	T	O_2	%
0.5	0.25	13	91	0.25	15	105	0.5	15	105
1	0.3	-	-	0.25	-	-	1	-	-
3	0.35	-	-	0.25	-	-	2	-	-
5	0.47	-	-	0.25	-	-	3	13.2	99
7	0.95	-	-	0.25	-	-	3.5	-	-
16	2.4	-	-	-	-	-	-	-	-
B + 1	4	10	77	0.25	-	-	3.6	8.8	67

Table 2. Temperatures °C taken in conjunction with benthos, Southern Indian Lake, 1972.

DATE	Region '0', July 1-2					Region 1, July 30						July 16
STATION	01	02	03	04	05	06	10	11	16	17	18	19
surface	16.5	17.8	18	16.5	16	16	16.5	17	16	16.5	16.5	17.9
0.5	-	-	-	-	16	16	16.5	17	16	16	15.5	17.9
1	16.3	17.2	17.8	16.3	16	16	16.5	17	16	16	16.5	17.9
3	16	16.5	16.8	16	16	-	16.5	17	16	16	16.5	17.5
5	16	-	-	16	16	-	16.5		16	16	-	-
7	16	-	-	15.9	16	-	16.5		16	16	-	-
10	-	-	-	-	-	-	16.5	-	16	-	-	-
bottom	15.8	15.9	16.7	15.8	16	16	14.5	16.8	14	15	15	17
depth (m)	7.5	5	4.5	9.7	8	1.6	17	3.8	21	9	3.5	5
substrate	2-6	2	1	2	5	5	-	5	1	5	5	1

	Region 2, July 5-6						Region 3, July 6-7					
	20	21	22	23	24	25	30	31	32	33	34	35
surface	16	17	16.5	17.9	17	18.5	16.5	16	16	15.8	15.9	18
0.5	-	-	-	-	-	-	16	-	-	-	-	17
1	15	15	16.2	17.9	16.2	18.5	15.2	15.5	16	15.5	15.9	16.2
3	14.9	14.9	15.8	-	15.9	-	15	15.2	15.7	15.2	14	14
5	14.5	14.8	15	-	15	-	14.9	15.2	15	15.1	-	-
7	14.5	14.5	14.1	-	15	-	14.5	15	13.5	15.1	-	-
10	14.5	14.5	12.1	-	14.2	-	14	14	11.5	15	-	-
bottom	14.2	14	-	17.2	14	18	14	11	9.2	13	13.1	14
depth (m)	19.7	11	14	3.1	18.5	2.5	19.6	15.5	14.5	13.6	3.5	3.7
substrate	1-6	1-4	1-4	1-2	1-6	1	1-3	1	1-2	1-2	2	2

Date	Region 4, July 7-9									Region 5, July 9 & 12					
Station	40	41	42	43	44	45	46	47	48	50	51	52	53	54	55
surface	15.8	18	15	15.6	16.8	17.1	15.2	16	16.1	15.2	16.1	16.5	17.2	15.9	15.1
0.5 m	15.6	17.3	15	15.1	16.8	17.1	15.2	16	16.1	15.2	16.1	16.5	17.1	15.9	15
1 m	15.5	17	14.9	14.9	16.2	17	15.2	15.3	16.1	15.2	16	16.5	17.1	15.9	15
3 m	15	13.2	14.9	14.2	14.9	16.2	15	14.4	16.1	14.8	15.9	16.5	-	15.1	14.9
5 m	14.9	12.8	14.5	13.8	11.8	14.8	13	14.2	16	14.4	15.2	-	-	-	14.8
7 m	14.7	11.9	14.5	12.4	10	-	10.9	14.1	11.2	13.2	12.9	-	-	-	-
10 m	12.3	11	12.5	9.2	8.1	-	8.9	13.5	-	10.2	9.2	-	-	-	-
Bottom	7	9	8	7.9	6.8	-	-	9.2	11	10	6.3	16.2	16.7	14.7	14.2
Depth (m)	21.8	15.3	18.1	12.4	15.9	6	22.8	18.4	7.5	10.7	16.6	4.4	2.6	3.7	7
Substrate	1-4	1-2	1-2	3-6	4	1	2	1-2	-	1	1-2	1	2	2-3	1-3

	Region 5, (cont.)			Region 6, July 3-4, 1972						
Station	56	57	58	60	61	62	63	64	65	66
surface	17	18	15.9	17.2	17	17.8	16.2	18	18.2	17
0.5 m	16.9	18	15.9	-	-	-	-	-	-	-
1 m	16.7	17.9	15.9	17.2	17	17.2	16.1	17.9	17.9	16.8
3 m	15.8	17	-	16	16.9	-	-	-	-	16.5
5 m	9.9	13.3	-	15	15.9	-	-	-	-	15.8
7 m	-	12.7	-	14.9	14.3	-	-	-	-	15.8
10 m	-	9.4	-	-	-	-	-	-	-	14.8
Bottom				14.5	14	16	15.2	16.8	16	14.2
Depth (m)				8.1	8.3	2.9	2.3	3	2.7	11
Substrate				1-2	1	1-2	2-6	1-2	1-2	2

Date	Region 7, July 15-16, 1972							
Station	71	72	73	74	75	76	77	78
surface	17.2	18	16.8	17	16.5	18	17.2	16.8
0.5 m	17	18	16.5	17	16.5	17.8	17.2	16.5
1 m	17	18	16.5	17	16.5	17.5	17	16.5
3 m	16.8	17.5	16.2	16.8	16.2	17.2	16.9	16.1
5 m	-	-	-	16.5	16.1	-	16.9	15.3
7 m	-	-	-	16.5	16.1	-	16.9	15
10 m	-	-	-	15.5	-	-	14.5	12.9
Bottom	-	-	8.2	13	13.9	-	12.7	11.5
Depth(m)	14	9	8.5	12	9.5	7.6	14.5	14.5
Substrate	1-2	1	5-6	1-2	1-2	1-2	1-2	1-2

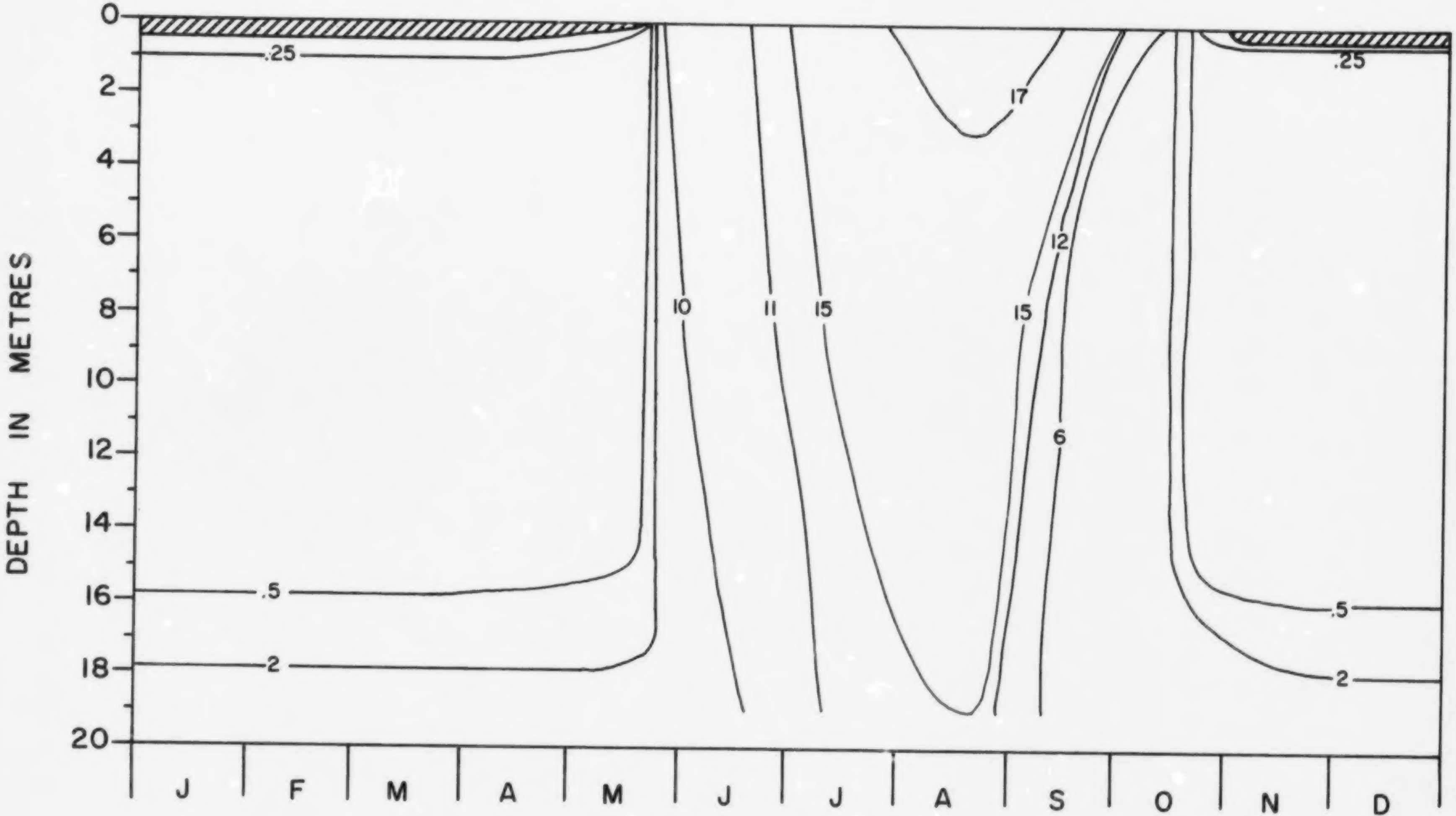
Table 3. Temperature ^{o}C taken in conjunction with zooplankton, Southern Indian Lake, August 26 - September 1, 1972. Abbreviations: m - meter; Substrate 1 - brown mud; 2 - grey clay; 3 - sand; 4 - gravel; 5 - rock; 6 - nodules; sfc - surface; B - bottom; Zm - maximum depth.

Station	01	02	03	04	05	09	10	11	12	13	14	15	16	17	18	19
surface	18	17.2	17.2	17.8	16.8	17.5	17	17.7	17	16.7	17.4	17.4	16.8	15.6	16	16.8
5 m	-	-	-	-	-	-	-	-	-	-	-	-	16.8	-	-	-
10 m	-	-	-	-	-	-	-	-	-	-	-	-	16.8	-	-	-
Bottom	17.6	17.2	17.2	17.6	16.8	17.5	16.8	17.5	16.4	16.7	17.4	17.4	15.2	15.3	16	16.8
Depth(m)	13	4.8	4.5	11.9	23	27	16	13.5	19	7	5	3	19	8	15	5.1

Station	20	21	22	23	24	25	30	31	32	33	34	35	40	41	42	43
surface	18	18.1	16.8	17.4	18.7	20.7	17.1	16.8	19.1	17.2	18.2	-	16.2	16.4	15.2	16.4
5 m	17.2	18	16.8	-	17.4	-	17.1	16.8	17.9	17.2	-	-	-	16.4	15.2	16.4
10 m	16.9	-	16.8	-	-	-	17.1	16.7	14.4	17.2	-	-	16	16.4	15.2	16.3
Bottom	16.5	17.5	13.1	17.3	17.3	19.8	16.9	16.7	14.1	17.2	18.2	-	14.8	16.4	14.6	14.2
Depth(m)	14	8	23	3	15	2.5	23	15	11	11	3.5	-	20	16	18	21

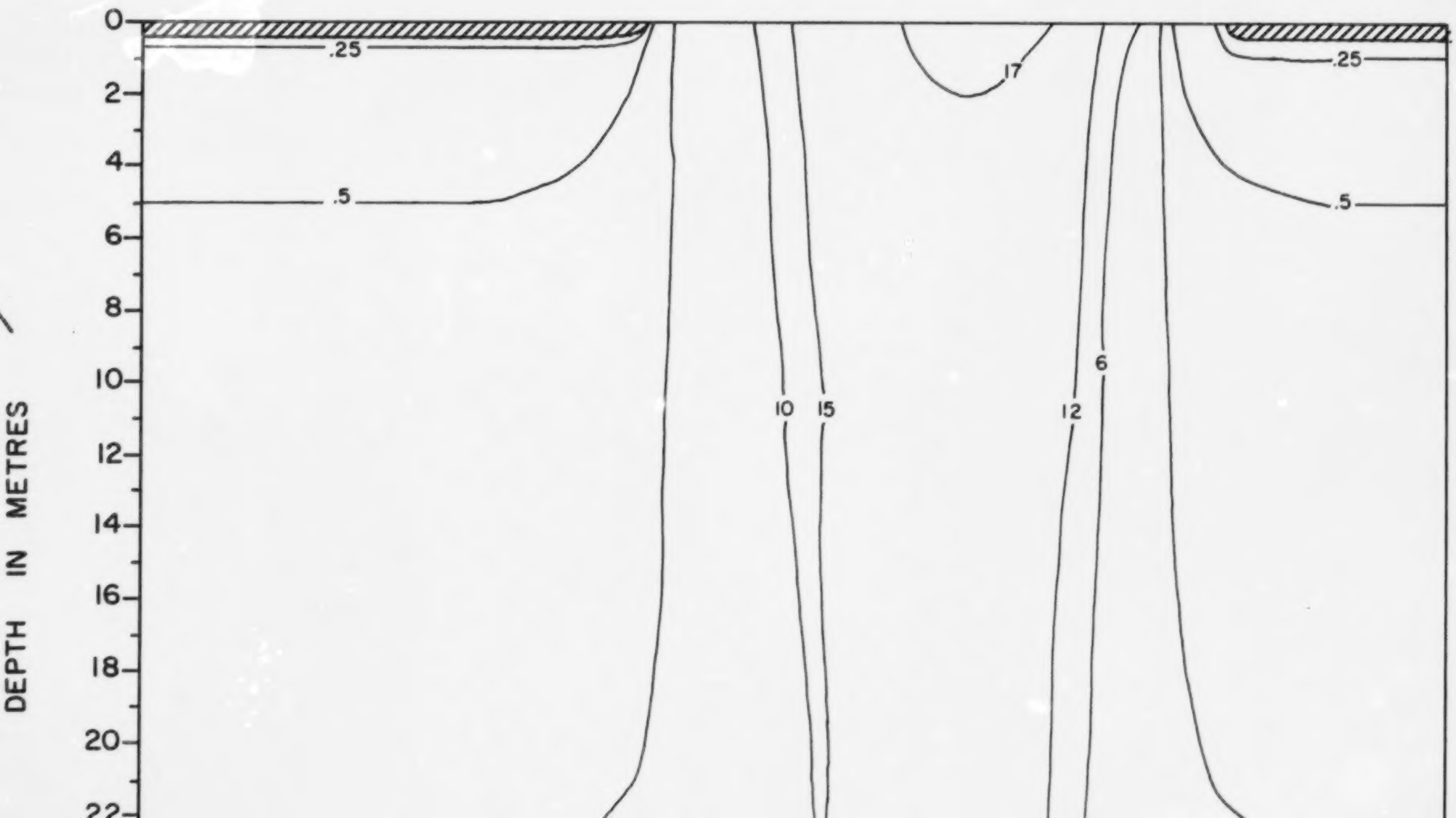
Station	44	45	46	47	48	50	51	52	53	54	55	56	57	58	60	61
surface	16.2	17.9	15.2	15.9	17.4	16.9	16.3	18.6	17.5	17.1	16.3	16.9	15.8	18.7	6.6	17
5 m	16.1	17.9	15.2	15.9	17.4	16.9	-	-	-	-	-	-	15.8	-	-	-
10 m	16	-	15	15.8	-	-	16.3	-	-	-	-	-	14.8	-	-	-
Bottom	15.2	17.9	15	15	17.2	16.5	14.3	18.6	17.5	17.1	15.9	16.8	14.3	18.7	15.6	16.5
Depth(m)	13	5	15	18	7.5	8.5	16	4	2.5	2.5	4.5	5	13	1.5	9.1	8.4

Station	62	65	66	73	74	75	77	78
surface	14	13.7	16.4	16	16.1	15.6	16	16
5 m	-	-	-	16	16.1	15.6	-	16
10 m	-	-	-	16	16.1	15.6	-	16
Bottom	14	13.7	15.4	16	16.1	15.6	15.5	15.8
Depth (m)	3	2.5	11.4	11	12.2	10	20	13.5



DEPTH IN METRES
0
2
4
6
8
10
12
14
16
18
20
J
F
M
A
M
J
J
A
S
O
N
D
.25
.5
2
10
11
15
17
12
15
6
.25
.5
2

Figure 1 . Temperature °C, Southern Indian Lake, Station 10, 1972-73.



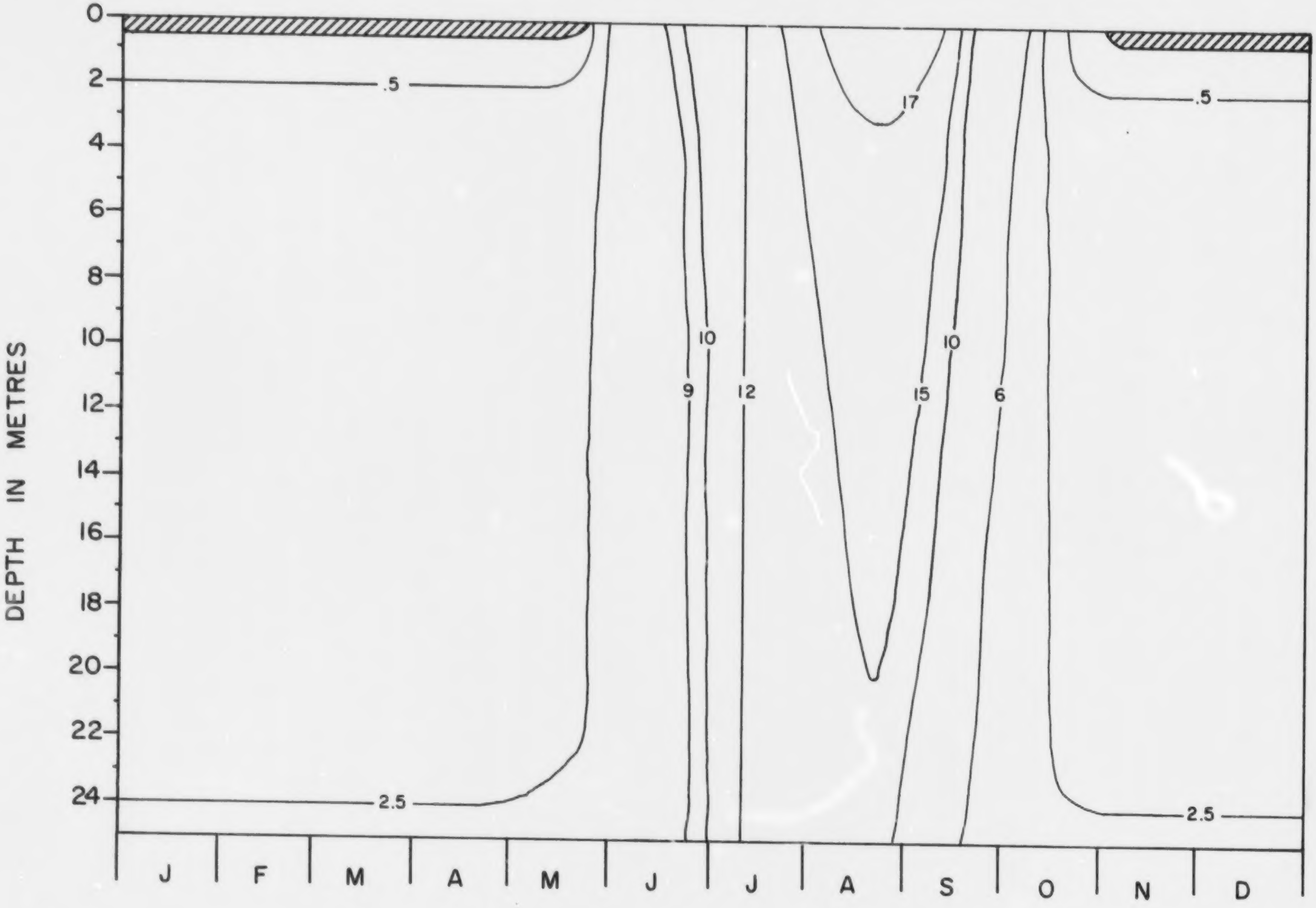


Figure 3 . Temperature °C, Southern Indian Lake, Station 30, 1972-73.

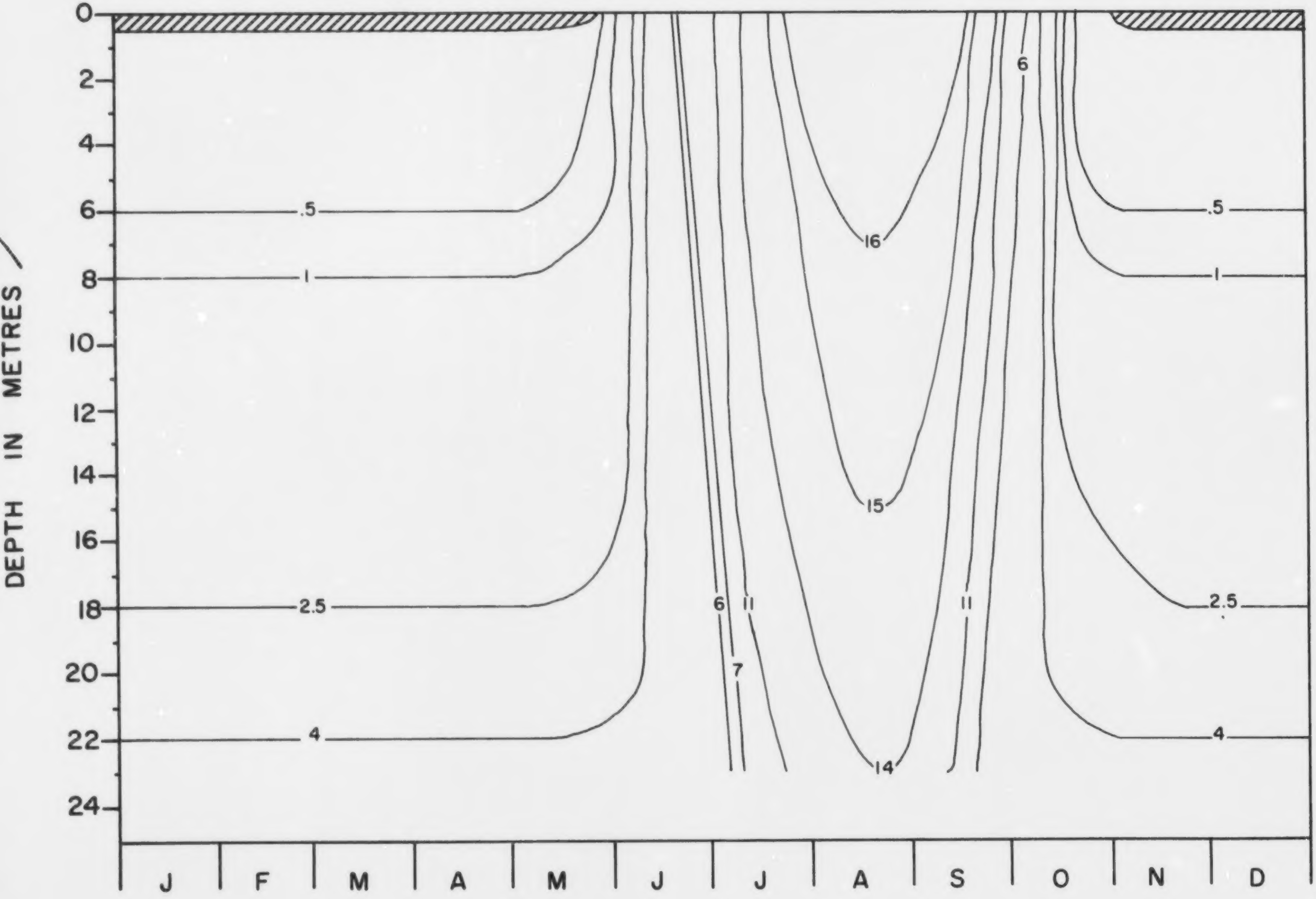


Figure 4 . Temperature °C, Southern Indian Lake, Station 40, 1972-73.

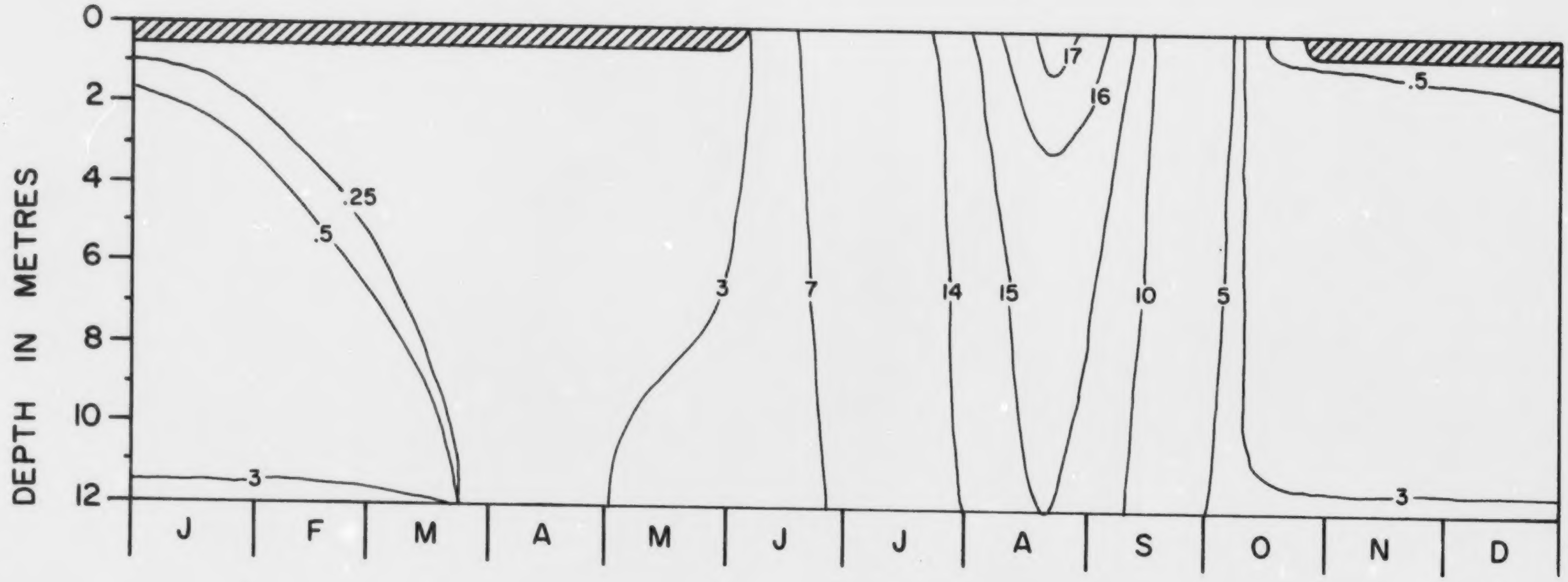


Figure 5 . Temperature °C, Southern Indian Lake, Station 50, 1972-73.

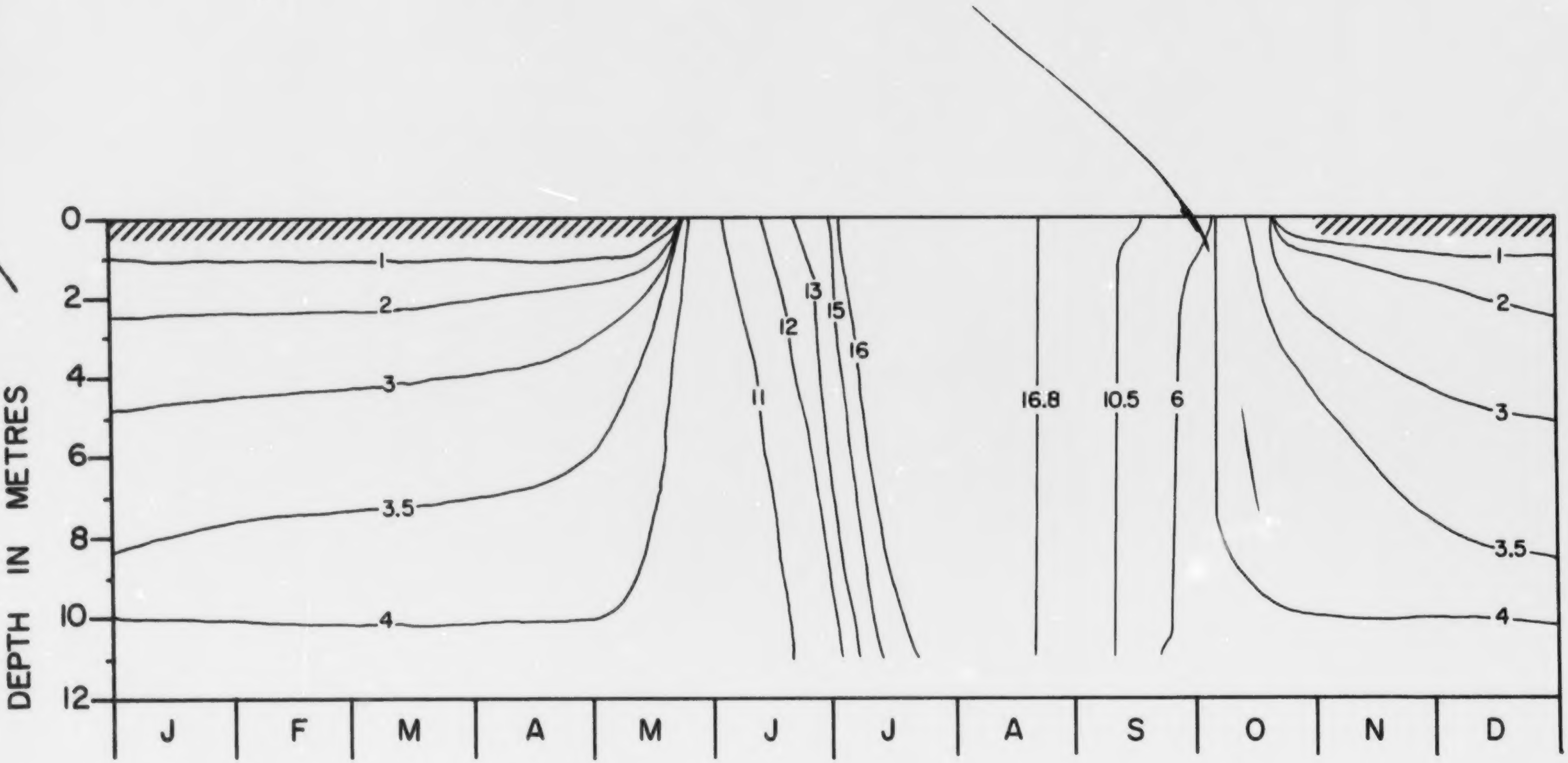


Figure . Temperature °C, Southern Indian Lake, Station 60, 1972-73.

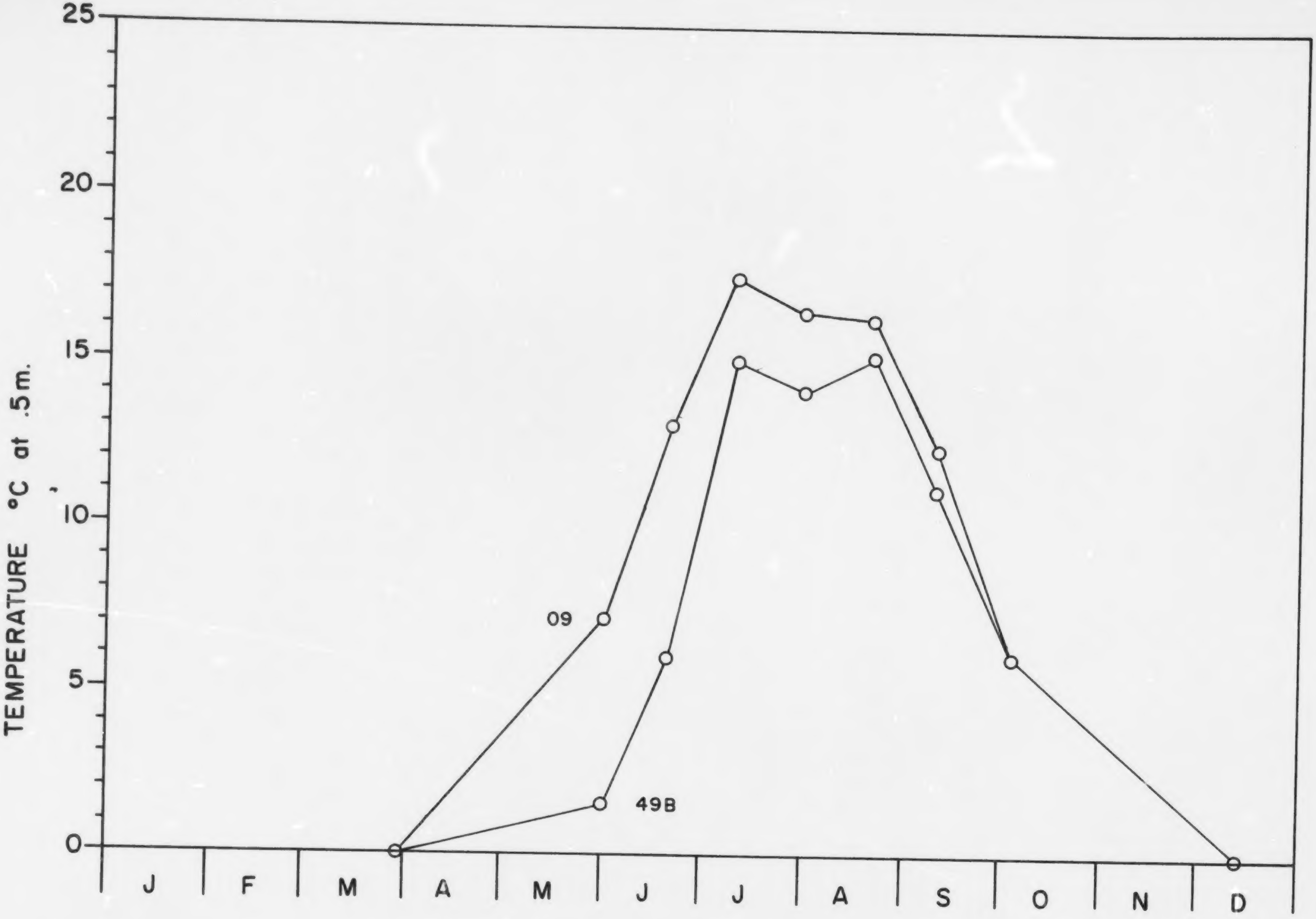
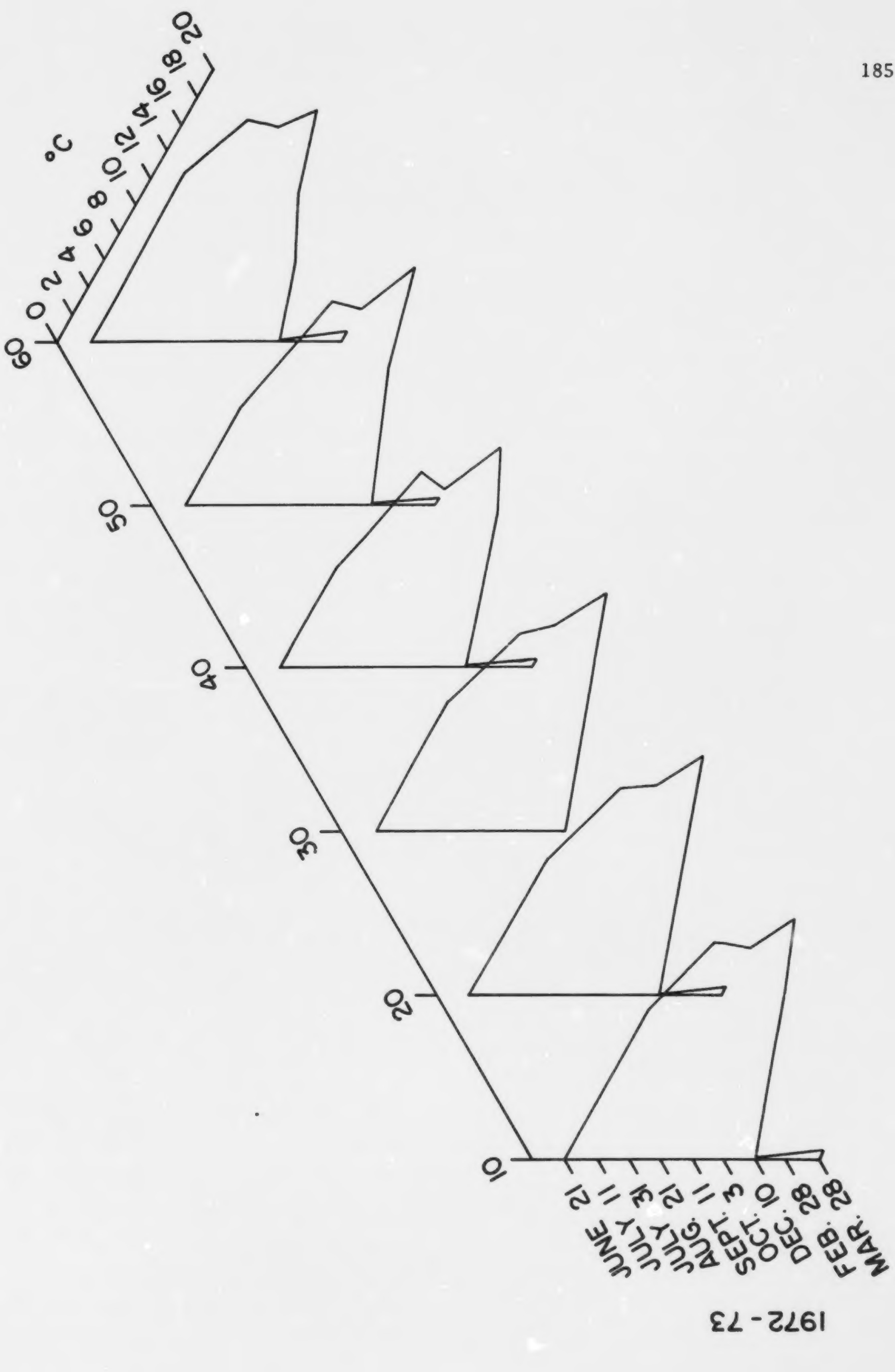


Figure 7 . Temperature comparison, inlet and outlet of Southern Indian Lake, 1972-73.


°C
0
2
4
6
8
10
12
14
16
18
20
60
50
40
30
20
10
JUNE 21
JULY 11
JULY 31
JULY 21
AUG. 11
SEPT. 3
OCT. 10
DEC. 28
FEB. 28
MAR. 28
1972 - 73

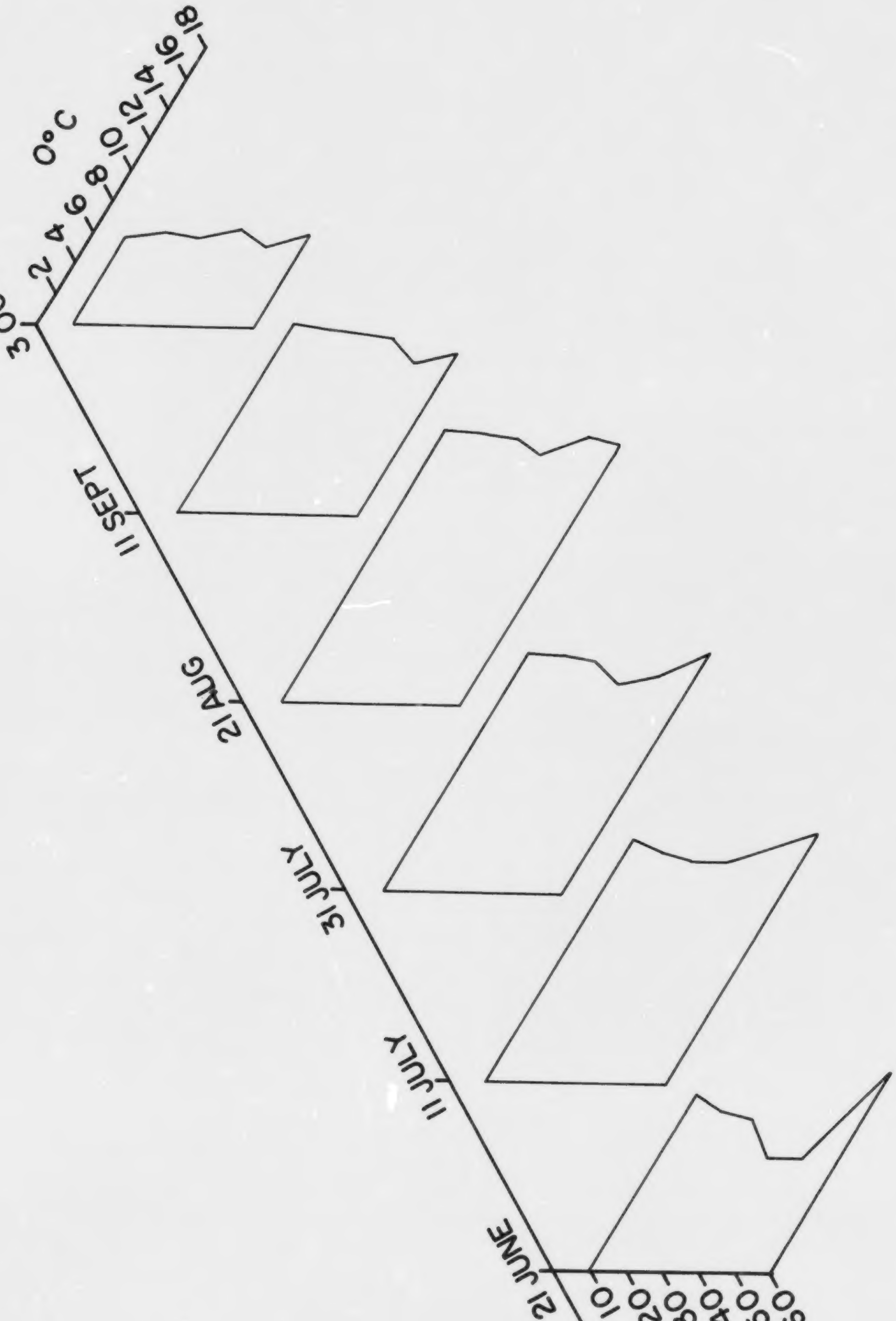


Figure 9 Temperature, Southern Indian Lake, 1972.

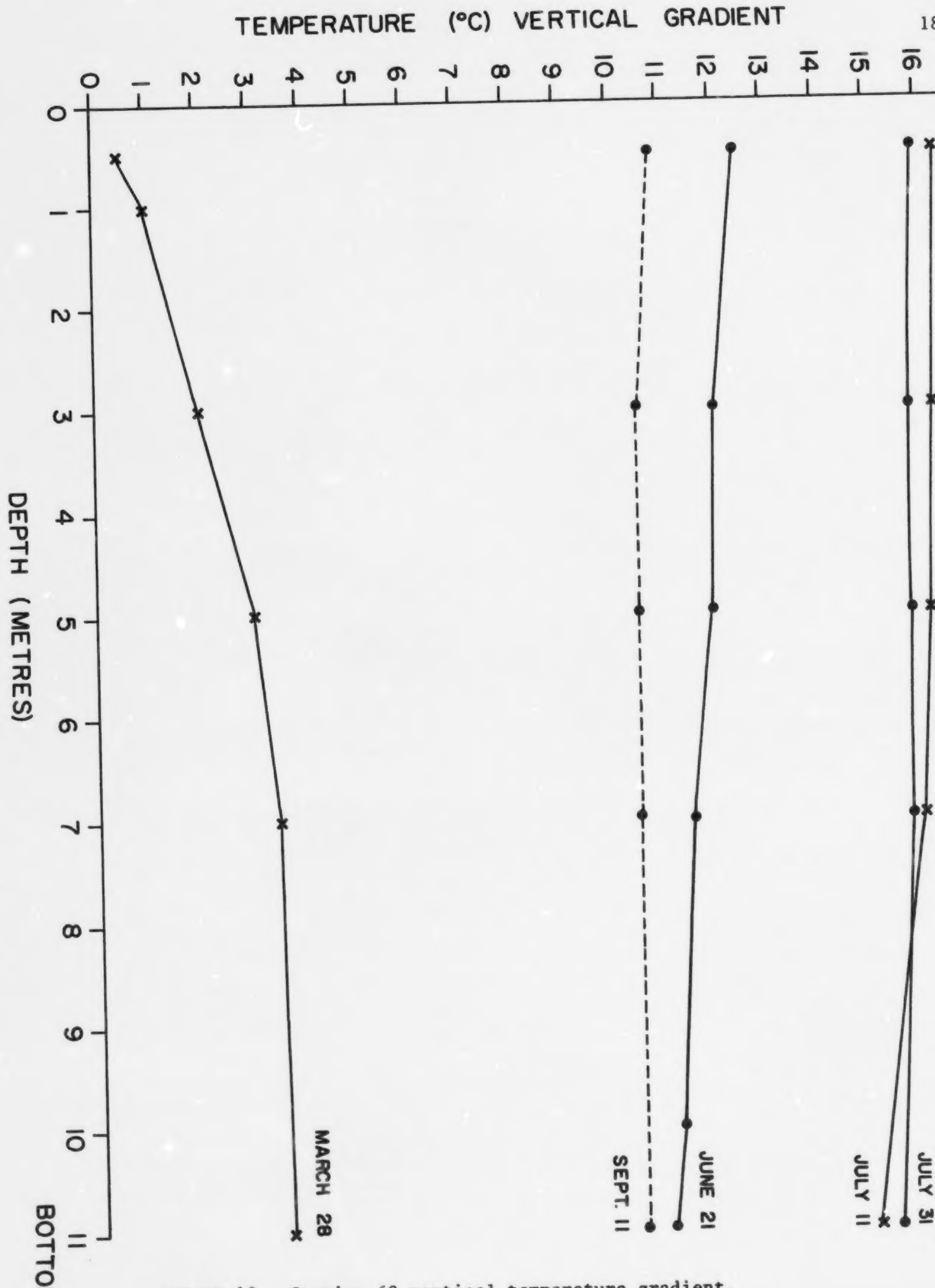


FIGURE 10. Station 60 vertical temperature gradient.

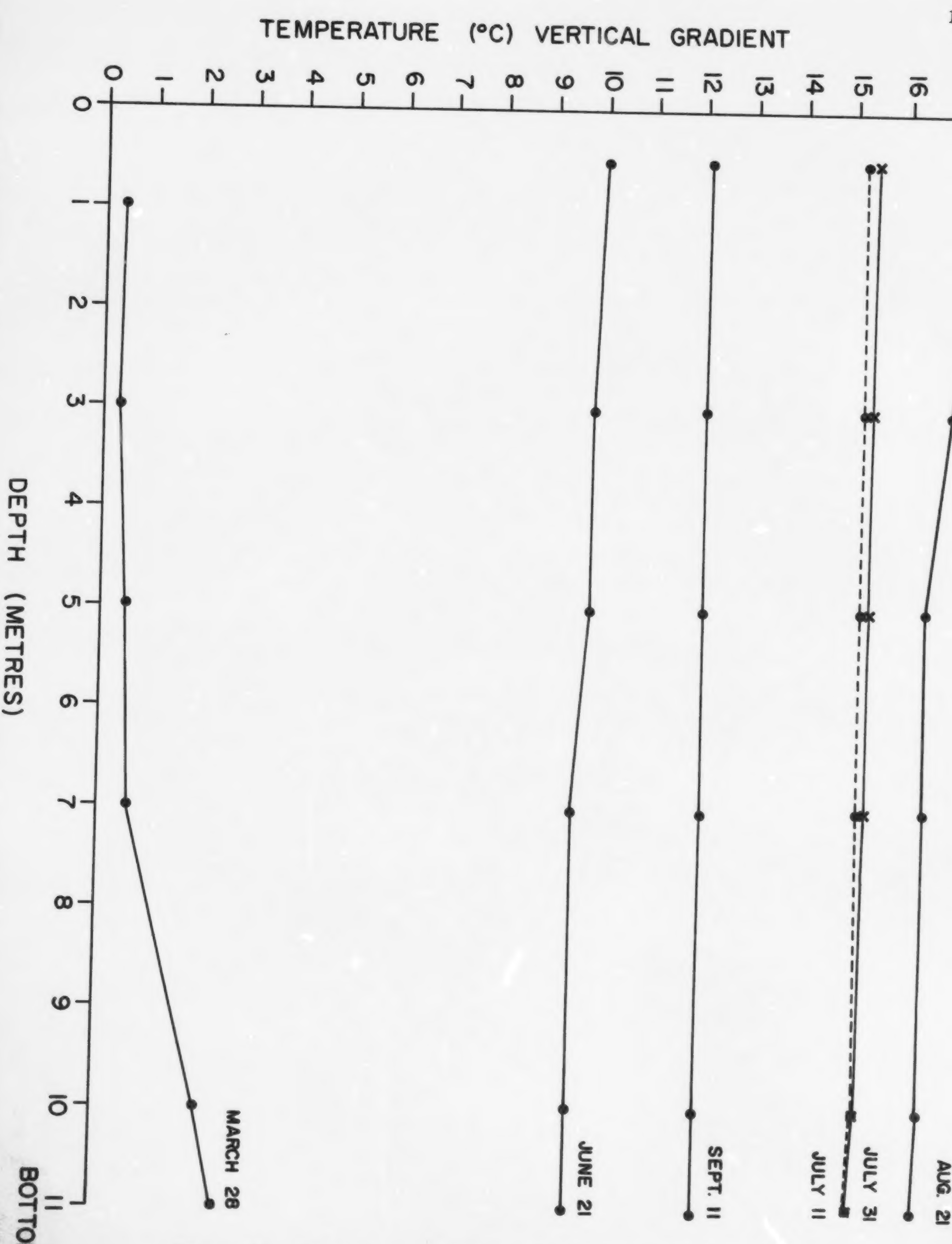


Figure 11. Station 20, vertical temperature gradient.

APPENDIX VI

Chemical Analyses of the Stream Survey Water Samples, Southern Indian Lake and Opachuanau Lake, 27 August, 1972.

Stream survey, Southern Indian Lake and Opachuanau Lake. Water chemistry analysis, 27 August 1972, depth 5 meters. Location of samples indicated on Figure

Region	0			-	1 & 7														
Stream	5A	5	111	09	8	11	12	19	20	21	22	30	34	35	36	106	107	108	109
Total CO_2 µg/1	564	319	755	543	860	769	755	477	1404	720	875	743	1325	1694	1205	1217	1468	1503	1430
Cl mg/1	1	1	1	1	<1	1	<1	<1	<1	1	1	1	1	<1	1	2	2	2	1
SO_4 mg/1	5	4	5	5	5	4	4	4	5	4	7	5	5	6	5	9	4	5	5
Si mg/1	1.3	0.7	0.4	0.8	0.8	1.4	1.3	0.8	1.7	1.3	0.6	1.5	1.4	0.7	0.7	2.9	-	1.8	2.0
Na mg/1	1.5	1.2	1.7	2.8	2.2	1.8	1.6	1.1	2.0	1.4	1.9	1.4	1.9	1.9	1.9	2.3	3.1	3.4	2.7
K mg/1	0.9	0.6	0.8	1.2	0.5	0.9	0.8	0.6	0.8	0.7	0.7	0.9	0.5	0.6	0.9	0.8	0.8	1	1.1
Mg mg/1	3.9	2.3	4.7	4.2	5.7	4.7	4.9	3.3	7.1	4.9	6.4	4.2	7.0	8.7	6.4	7.2	7.7	9.9	7.7
Ca mg/1	10.1	6.2	11.6	9.5	14.5	13.6	14.0	9.3	19.6	13.9	16.8	13.4	24.5	30.4	20.5	25.5	23.7	28.1	24.2
Mn mg/1	0.03	0.01	0.01	0.01	0.03	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01
Fe mg/1	0.2	0.2	0.3	0.1	0.2	0.2	0.1	0.2	0.5	0.2	0.2	0.3	0.4	0.3	0.3	0.3	0.1	0.2	0.4
Colour	50	20	50	10	50	20	20	40	80	40	60	40	70	80	60	70	40	50	60
Temp °C	19	19.5	17.5	17	18	17.5	16.5	18.5	14.5	18.5	16	18.5	15.5	15.5	15	11.5	16	16.5	15.5

Region		0								1 & 7									
Stream	5A	5	111	09	8	11	12	19	20	21	22	30	34	35	36	106	107	108	109
NO_3-N µg/l	11	7	8	5	6	53	19	8	5	13	8	7	4	7	12	7	11	3	8
TDN µg/l	258	286	556	299	735	477	323	275	270	297	518	352	440	488	356	323	634	496	527
Susp N µg/l	136	55	74	75	124			73	69	74	86	92	55	172	72	42	155	31	211
TDP µg/l	10	4	17	3	23	3	6	16	6	10	2	10	11	14	7	8	3	7	25
Susp P µg/l	17	5	8	8	-	26	5	7	7	7	8	13	11	9	12	4	23	5	13
Cond µmoles/cm	71	50	95	85	105	100	104	68	145	102	152	94	163	200	140	159	170	203	167
pH	7.6	7.6	7.4	7.8	7.3	7.7	7.9	7.5	7.0	7.8	7.6	7.4	7.2	7.4	7.1	7.7	7.4	7.9	7.4
TDS mg/l	43	24	92	74	67	51	41	39	104	52	91	59	16	135	87	102	130	178	128
TSS mg/l		4	1	7	6	23	15	5	2	5	2	7	5	12	5	1	9	4	28
Susp C µg/l	890	1050	720	650	<4000	4040	3790	880	720	730	1070	800	850	2330	840	460	1520	530	2580
DOC µg/l	876	613	1195	545	1205	700	814	855	1298	912	1222	906	1201	1407	1154	1046	1263	1040	1076

Region	West side of 3 and 4				East side of 2, 3 and 4								Missi
Stream	42	44	45	48	81	87	90	91	92	97	99	100	49B
NO_3-N	7	9	5	4	5	8	15	7	5	4	10	9	6
TDN	299	539	627	203	340	516	388	341	341	324	275	463	226
Susp N	73	62	88	154	29	36	18	39	42	30	32	55	132
TDP	8	1.5	25	5	7	23	20	11	18	1	10	14	10
Susp P	7	11	15	15	5	6	4	7	8	8	10	7	8
Cond	112	80	95	92	120	102	114	152	230	180	200	221	75
pH	8.0	7.5	7.5	7.9	7.8	7.6	7.8	7.4	7.6	8.1	8.0	7.5	8.0
TDS	106	73	67	39	98	147	125	183	128	117	109	123	55
TSS	6	7	1	5	2	2	2	2	4	3	10	6	1
DOC	990	1133	1684	839	1334	1720	1391	1241	1102	1051	639	1200	535
Susp C	660	660	880	1420	510	460	290	540	580	450	500	610	850

Region	West side of 3 & 4				East side of 2, 3, and 4								Missi
Stream	42	44	45	48	81	87	90	91	92	97	99	100	49B
Total CO_2	863	649	644	620	1088	722	904	1211	1726	1398	1588	1737	537
Cl	1	1	2	1	1	1	1	1	2	<1	<1	1	1
SO_4	5	5	6	4	4	5	7	5	2	3	2	2	4
Si	0.4	0.5	0.4	0.3	1.8	2.2	1.5	1.8	2.2	1.9	2.1	0.9	0.6
Na	1.5	1.3	2.0	1.2	1.2	1.2	2.4	1.5	2.6	2.2	1.8	3.1	2.3
K	0.7	0.7	0.6	0.5	0.5	0.6	0.5	0.4	0.7	0.5	0.7	0.6	1.0
Mg	5.1	3.8	4.8	4.0	5.9	4.7	5.2	6.6	9.3	7.4	8.6	9.8	3.4
Ca	17.1	11.1	12.9	12.8	20.3	16.5	18.9	23.4	34.0	28.6	30.7	31.3	8.3
Mn	0	0.01	0.01	0	0.02	0.01	0.02	0.02	0.02	0.03	0.01	0.01	0.01
Fe	0.15	0.22	0.50	0.18	0.17	0.43	0.41	0.23	0.25	0.16	0.20	0.35	0.08
Colour	20	40	100	20	80	>100	80	70	40	50	20	50	10
Temp	17.5	17	16.5	18.5	15.5	13.5	14	16	16	14	15.5	15.5	14.5

Region	5										6					
Stream	58	61	63	64	70	71	73	75	76	79	101	102	103	104	105	106A
NO_3-N	35	65	5	6	4	4	7	13	5	8	4	5	5	9	3	4
TDN	259	460	451	513	334	345	343	336	297	309	567	228	440	371	329	325
Susp N	111	79	65	83	154	74	99	78	55	32	66	50	34	51	57	35
TDP	2	15	7	17	22	19	15	42	13	11	8	4	7	8	5	8
Susp P	12	19	10	7	14	4	6	5	7	8	7	8	10	8	8	8
Cond.	125	190	85	94	42	84	106	120	87	122	182	220	175	134	110	195
pH	7.9	8.0	7.9	7.4	7.1	7.3	7.5	7.9	7.9	7.8	7.9	7.6	7.8	7.6	7.3	7.6
TDS	89	102	66	63	43	98	101	91	76	93	143	164	147	130	106	162
TSS	7	9	6	4	8	3	33	9	3	2	2	2	4	1	5	5
Susp C	800	850	490	910	1710	490	1320	1200	690	500	720	570	510	760	580	490
DOC	881	948	989	1339	1277	1545	1391	1241	948	1030	1277	1286	1226	1391	1344	1226

Region	5										6					
Stream	58	61	63	64	70	71	73	75	76	79	101	102	103	104	105	106A
Total CO_2	886	1530	597	758	246	632	796	910	611	910	1562	1673	1433	1073	980	1597
Cl	1	2	1	<1	<1	<1	<1	1	<1	1	3	3	1	1	1	2
SO_4	4	4	4	4	4	5	5	8	3	4	4	5	4	4	5	7
Si	0.8	1.5	0.7	0.6	0.6	1.6	1.5	1.9	0.8	1.5	0.8	1.5	0.7	1.6	1.4	3.1
Na	1.2	1.7	1.0	1.4	1.0	1.3	1.8	3.0	0.8	1.2	3.1	2.6	2.7	2.0	1.9	2.7
K	0.4	0.7	0.3	0.4	0.4	0.5	0.4	0.5	0.3	0.7	0.3	0.6	0.6	0.4	0.7	1.0
Mg	5.6	8.2	3.7	4.6	2.3	4.2	5.4	5.9	3.8	4.9	8.0	10.3	8.6	6.3	5.5	9.2
Ca	18.1	28.1	13.1	13.3	5.6	11.9	15.0	18.7	12.9	18.9	27.0	31.8	28.7	19.7	17.8	29.7
Mn	0.01	0.01	0.01	0.02	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.02	0.01	0.02	0.01	0.03
Fe	0.13	0.20	0.16	0.42	0.34	0.42	0.21	0.25	0.11	0.14	0.17	0.21	0.20	0.21	0.41	0.36
Colour	20	50	50	80	80	100	80	70	40	50	30	50	40	60	80	60
Temp	16.5	16	17.5	16.5	16	13.5	15.5	14.5	16	14.5	16.5	15.5	15.5	16.5	16.5	16

APPENDIX 5 - VOL. 1 - D.

SOUTHERN INDIAN LAKE:
SEDIMENTARY ENVIRONMENTS, RECENT BASIN HISTORY AND IMPLICATIONS OF INUNDATION AND DIVERSION

SOUTHERN INDIAN LAKE: SEDIMENTARY ENVIRONMENTS, RECENT BASIN HISTORY AND IMPLICATIONS OF INUNDATION AND DIVERSION

by

R. E. HECKY
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
February, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

ABSTRACT

Numerous sediment collections were made in Southern Indian Lake in 1972 in connection with other tasks. The information gathered from these collections is summarized in this section in an attempt to determine present sedimentation patterns in the lake. Sediment cores from three stations allow the recent history of the lake to be elucidated. Knowledge of the present and past patterns of sedimentation is used in an attempt to forecast the eventual fates of sediments which will become available from shoreline erosion after inundation and diversion. The probable impact on turbidity and sedimentation of the different shoreline types classified and provisionally mapped by the Physical Impact study is evaluated, and the probable impact on specific regions is predicted based on the dominant shoreline type in any region and knowledge of present sedimentation in that region.

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Table 3.7. Principle shoreline types on Southern Indian Lake and their probable contribution to sedimentation and impact ....

ACKNOWLEDGMENTS

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3.1. INTRODUCTION

The character and distribution of sediments within a lal yield insight into the physical structure and biogeochemical fu of the lake basin ecosystem. Although an exhaustive survey of sediments in Southern Indian Lake was not undertaken by the Fis Limnology component, a substantial amount of information was ge ancillary to the various major tasks, especially the benthic su (Hamilton, 1974). A very limited coring program was also condu March 1973, in order to obtain a temporal perspective on the st of the system, i.e. whether under natural conditions there are variations in sources of sediment, basin productivity and spec of microfossils incorporated in the sediments. It was also hop these sedimentological studies, limited as they were, would al insight into the probable fate of sediments released during th of new shorelines after impoundment.

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3.2. METHODS

The benthic survey conducted during July 1972 collected Ekma
dredge samples from 53 stations in Southern Indian Lake, Opachuanau
and the Churchill River below Leaf Rapids (see Fig. 3.1 for locatio
These samples were subjectively described in the field according to
and dominant constituents, e.g. rock, gravel, sand, fine materials
and clays), or combinations of these (Table 3.1). Subsamples of fr
sediment from 10 stations were returned to the Freshwater Institute
determination of total carbon, nitrogen, and phosphorus content.
Estimation of inorganic carbon (carbonate) concentration was also do
that organic carbon content could be calculated by difference. The
methods for the determination of total carbon, nitrogen, and phospho
described in Brunskill et al. (1971). Sedimentary carbonate was dete
by acidification with concentrated H_2SO_4 in a sealed vial, partition
the dissolved CO_2 into a helium gas phase, and estimating CO_2 evolve
gas chromatography (Stainton, 1973). Fossil diatom slides were ma
sediment subsamples from eight stations. Slides were prepared by t
method described by Stockner (1971).

In March 1973 three sediment cores from stations 10, 40, and
were retrieved with a Mackereth corer (Mackereth, 1969). Total carbo
nitrogen, phosphorus, and carbonate-carbon were determined by the afo
mentioned methods at one cm intervals near the surface and at 10 cm
intervals at greater depths in the cores. Fossil diatom slides were
prepared semiquantitatively by removing 1 ml of sediment from the cor

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with a plastic syringe and preparing slides by the above me
keeping a record of the dilutions required to yield a conve
of diatom frustules on a slide.

3.3. PATTERNS OF SEDIMENTATION

Bottom materials in Southern Indian Lake are extremely heterogeneous and range from solid rock to fine clays. Distribution of sediment types as encountered during the benthic survey is presented in Figure 3.2. Figure 3.3 gives a generalized distribution of sediments indicated by the benthic survey and all other sediment sampling experience on the lake. The "average" sediment type within a given area is indicated and thus some of the detail of the benthic survey is lost. Further discussion will center on the sediments encountered by the benthic survey only. The typology of sediments given in Figure 3.2 is based on the size of the coarsest material recovered in significant amounts. Many of the dredge samples were complex mixtures of all the sediment types listed indicating a high degree of temporal variability in the depositional environment at those stations.

The size of sedimentary particles recovered at a given station should reflect the availability of particles of a given size and the turbulence of the overlying water with the size of deposited particle increasing with increasing turbulence. At several stations, e.g. 30, 22 and 43, sediments ranging from gravels to silts were recovered in a single dredge sample. At least two dredge samples preserved the *in situ* stratigraphy of the sediment. At station 21 a fine brown "ooze" was found overlying gravel while at station 54 sand was observed over clay. It is possible that the stations with complex mixtures had a similar stratigraphy destroyed in the sampling process. The time scale of variation which produces these mixed samples cannot be estimated from the available information. Figure 3.2 gives a static view of the distribution of sediment types, and it must be remembered that many of the sedimentary environments are more dynamic through time than can be appreciated from this figure.

Although temporal variability renders generalization about sediment distributions difficult, a few discernible basic patterns are evident. The two stations in the Churchill River encountered rock bottoms which are presumably kept swept clean by the river currents. Inshore areas such as protected bays in the main lake and nearly all of region 6 and region 7 stations have fine grained sediments. In the protected bays off the main lake and the entire region 7, low turbulence resulting from limited wind fetch would favor the accumulation of fine sediments. Region 6, South Bay, is much more exposed to the wind, but the surficial terrestrial deposits exposed in the basin are largely glaciolacustrine clays. As this is the predominant material available for transport, the fine nature of bottom sediments is not surprising. The elongated bays to the east of South Bay (stations 62, 63, and 64) appear to be the most significant sources of sediment to South Bay. Waters in these areas are slate grey from their high load of suspended materials derived from the erosion of clay banks.

Within the main lake, regions 1 through 5, sediment types are much more variable. Many deep, offshore areas have coarse sediment while shallow, inshore areas have fine materials. This contrasts sharply with the situation found in the south basin of Lake Winnipeg, where Kushnir

(1970) found a very simple concentric distribution of sediment types ranging from inshore sand and gravels through silty clays to nearly pure clays in offshore stations. This distribution results from the distribution of wave and current energy in a morphometrically simple basin. Highest energies are found inshore where shoaling waves and longshore currents prevent the deposition of fine sediments inshore and transport them offshore. As the water becomes deeper deposition of finer sediments is favored as turbulence generated by wind-water interaction at the surface is rapidly dissipated with depth by frictional resistance. The simple distribution of sediments found in Lake Winnipeg does not occur in Southern Indian Lake because of the differences in basin morphometry. Southern Indian Lake has a complex shoreline and a very irregular bottom attested to by the great number of islands (Cleugh *et al*. 1974). These islands represent sources of coarse sediments as well as areas of high turbulence due to breaking waves.

The effect of irregular bottom topography and shoreline is demonstrated by the depth relationship of sediment types (Table 3.2). As mentioned above, in simple cases an inverse relationship between grain size and depth would be expected because greater depth means that more energy is dissipated by the movement of water and less is available to do tractive work against the bottom. In Southern Indian Lake rocky and sandy sediments are restricted to shallow depths, but gravel is found over a large range of depths (Table 3.2). (It must be remembered that the typology is based on the coarsest particles encountered, and sediments classed as gravels also could have substantial amounts of sand present.)

In fact the mean depth of gravel containing samples is greater than that of fine materials. Also the mean depth of gravel containing sediments is greater than the mean depth of the lake suggesting that the deepest areas may not be areas of deposition for fine sediments and may themselves be the result of erosive forces. Conversely fine sediments may be found from very shallow to deep environments. The conclusion to be drawn from Table 3.2 is that nearly any sediment type may be found at any depth especially in the main regions of the lake. The type found is not a simple function of depth as it would be in a simple basin, but rather it is a complex function of basin morphometry and exposure to wind. This observation is pertinent to the probable distribution of suspended materials derived from shoreline erosion after impoundment. As the morphometry of the lake will be altered by impoundment, the present distribution of sediments may be a poor guide, albeit the only one available, to post-impoundment distribution. This is especially true in view of the natural temporal variability at many stations mentioned above.

An additional source of turbulence to consider in some parts of Southern Indian Lake is that due to the current engendered by the hydrographic slope (the height of inflow above the outflow divided by the distance between them). In most of the lake this current will be negligible because the momentum of water entering the lake at Opachuanau Rapids is distributed over the larger channel cross-section available in the lake. As the advective transport of water by the hydrographic slope is nearly constant (31,500 cfs at Opachuanau to 35,500 cfs at Missi Falls) through the main part of the lake, slope current velocity will be approximately proportional to channel cross-section by the relation:

$$\text{Slope current velocity (ft/sec)} = \frac{\text{Transport (ft}^3\text{/sec)}}{\text{Channel cross-sectional area (ft}^2\text{)}}$$

Calculation of this relationship revealed that only in channel constrictions, roughly delineated by the assigned boundaries between regions, could the slope engendered current constitute a significant fraction of the wind generated currents to be expected in offshore areas. These channel constructions are also the sites of ice-free or slush-ice areas in the winter (Cleugh, 1974). In these areas the lack of fine sediments may result from the activity of the slope current. These areas can be quite deep although narrow, and this may partially account for the fact that the deepest areas of the lake often have coarse sediments.

At several stations in the lake (marked with an asterisk in Table 3.1), small, dark brown pebbles were found in dredge samples. These pebbles were found to be friable under applied pressure which suggested an accretionary origin. Several of these pebble samples were sent to Dr. Brian St. Jean of the Canada Center for Inland Waters for chemical analysis. He confirms that these pebbles are ferro-manganese nodules. These nodules are formed by the precipitation of iron and manganese oxides on a preexisting nucleus such as a sand grain. Their growth is generally very slow (Cronan and Thomas, 1972) and formation of these nodules requires that sedimentation rates at sites of formation be negligible otherwise the forming nodules would be buried and growth terminated. Presence of these nodules at a station can be used as an indication that there is presently little sediment accumulation at that location. From Table 3.1 it can be noted that some nodule containing samples are from deep stations which reinforces the conclusion drawn above about depth and sedimentation relationships.

3.4. GRAIN SIZE ANALYSIS AND MINERALOGY

Grain size analysis and determination of the mineralogical composition of the sediments was limited to the three stations where cores were taken. The results of these analyses are presented in Table 3.3. Station 10 in region 1 should be representative of the sediments brought in by the Churchill River to the main body of the lake and deposited soon after influx. Station 40 in region 4 should reflect the material deposited just before the lake waters exit the lake. The differences between these two stations will give some indication of the kinds of sedimentary processes which have taken place in the lake. Station 50 is unaffected by the Churchill River and can demonstrate the sediment produced by a local Shield drainage system.

There is a substantial difference between the particle sizes of surficial sediments of stations 10 and 40. Station 10 has a much higher proportion of silt-sized particles than station 40. This indicates that a significant portion of the coarser material which the river keeps in suspension settles out upon entering the less turbulent lake environment. By the time inflowing waters reach station 40 the suspended load consists of much finer material than that which enters from the river. Station 50 has a grain size composition similar to that of 40 except that sand is a significant proportion of the total material. The higher sand content is contributed from the sandy overburden in this region where there is an extensive esker complex. As mentioned previously a wide range of sediment sizes may also indicate a relatively high degree of temporal variability in sedimentation at this site.

There are not striking differences in either the quantitative or qualitative mineralogical composition of the three stations. The sands and silts are largely plagioclase feldspars and quartz while the clays are primarily illite with significant amounts of chlorite and inconsequential amounts of montmorillonite. This clay mineral assemblage is quite different from that found in the recent sediments of the south basin of Lake Winnipeg where Kushnir (1970) found montomorillonite to be dominant. However the mineralogical composition of the Southern Indian Lake clays is similar to that which Kushnir found for Pleistocene glacial and glacio-fluvial clays which are exposed and eroded in the Winnipeg basin. The Cretaceous shales on which the Churchill River arises in Alberta and Saskatchewan are dominated by montmorillonite (various studies cited in Kushnir, 1970) and the very insignificant amounts of montmorillonite found in Southern Indian Lake indicate that most of the prairie-derived suspended material has been deposited before the river reaches Southern Indian Lake. The suspended materials introduced to the lake and deposited in the lake are derived from glacial and glacio-lacustrine deposits on the Precambrian Shield in Saskatchewan and Manitoba. The only notable difference between station 50 sediments and the two stations in the main lake is the presence of dolomite at station 50. This dolomite must be derived from local carbonate deposits in the Waddie River basin which drains into Region 5.

3.5. SEDIMENTARY CARBON, NITROGEN, AND PHOSPHORUS

The distribution of carbon, nitrogen, and phosphorus in surficial sediments (Table 3.4) defies simple explanation. This is not unexpected in view of the complex sedimentation patterns discussed above. Organic carbon ranges from 7.8 to 49.5 mg/g, carbonate carbon from 0.6 to 8.9 mg/g, nitrogen from 1.3 to 7.1 mg/g, and total phosphorus from 0.9 to 2.0 mg/g. The variability possible over a relatively small area is demonstrated in Table 3.5 where values for surface sediments from cores and dredges taken in the same area are given. Concentrations of C and N are not simply depth related as comparison of the values for stations 20 and 30 which have the same depth show. The two main lake stations, 30 and 40, with lowest C and N concentrations both have coarse material present in the sample (Table 3.1) suggesting an inverse correlation between grain size and organic content. Such a correlation is often observed in lakes because the fine size and low density of organic materials favor a "winnowing" of organic detritus from turbulent depositional environments to low energy environments. In Southern Indian Lake the quiet environments are not necessarily the deepest. The low organic carbon concentration at station 60 cannot be explained in this manner as the sediment was a fine clay. The very low algal productivity (Hecky et al. 1974) of this region is likely responsible, although knowledge of sedimentation rates is required to substantiate this.

Among the components analyzed, total phosphorus exhibits the least variability with the maximum and minimum values differing by only a factor of two. Total nitrogen varies by a factor of 4.5x, organic carbon by 6.3x, and carbonate-carbon by a factor of 15x. Calculation of mole ratios of these elements reflect this variability with C:N ratios (org carbon) being much less variable than C:P (organic carbon) ratios. Cl in this lake deposition of phosphorus and organic materials are not cl linked suggesting that much of the P is associated with the mineral components. This conclusion was also reached by Brunskill *et al*. (197 for sediments of Shield lakes in northwestern Ontario. Brunskill *et a* were not able to identify the state of phosphorus in sediments despite more extensive analyses than are available for Southern Indian Lake.

Organic carbon-nitrogen ratios are often used as an index of the relative contribution of terrestrially derived organic material to a la and its sediments (Hutchinson, 1957, p. 886). High C:N ratios (organic carbon) reflect a dominance of terrestrial drainage while lower values indicate a high degree of autochthony (organic materials produced withi the lake). The values for total carbon-nitrogen ratios found in Southe Indian Lake (Table 3.4) are generally similar to those reported by Brunskill *et al*. (1971) for lakes in the Experimental Lakes Area where values for total carbon:nitrogen ratios range from 8.4 to 13.9 with a mean of 11.8. The range for Southern Indian Lake is comparable but the mean, 10.4, is somewhat lower. The C:N ratios (total carbon) of Lake Winnipeg sediments are much more variable (G.J. Brunskill, personal communication) with a range from less than seven up to 40. Lowest value less than the 12, are found in offshore sediments while higher values, greater than 12, are found inshore. The highest values, up to 40, are encountered off the mouths of the Winnipeg and Red Rivers in the South Basin of the lake. Comparing these results, one could say that terrestrially derived organic materials appear to be a relatively small component of the total organic deposition in Southern Indian Lake. The C:N ratio (organic carbon) is much less variable than the lithology of the sediments. Lithology is apparently quite responsive to local depositional processes which also affect the amounts of organic material incorporated. The organic detritus itself, however, is fairly similar all over the lake. The high variability observed for carbonate carbon may be attributed to the uneven distribution of relatively carbonate-rich glacio-lacustrine clays in various parts of the drainage basin.

3.6. DISTRIBUTION OF DIATOM MICROFOSSILS

Sediments can be a repository for diatom frustules after dea and offer an advantage over instantaneous phytoplankton samples in several years production are integrated in a single sediment sample Sediment assemblages offer the opportunity to check the representat of a single seasonal sampling by comparing results against the sedi record. The relative taxonomic composition of surficial assemblage broadly similar for most of the stations (Table 3.6). Species of *Melosira* are most abundant taxa with *M. islandica* and *M. italica* respectively the most numerous. These species tend to be found in trophic waters (Lund, 1962). *M. ambigua* and *M. granulata* which a generally considered more characteristic of eutrophic waters are of importance in surficial sediments. Region 4 has the highest abunda *Melosira* which corroborates the relative abundance of phytoplankton observed in 1972 when the highest standing crops of *Melosira* on abs and relative bases were observed in region 4. *Asterionella formosa* *Stephanodiscus* spp. (primarily *S. astrea* and its variety *minutula*), *Fragilaria* spp. constitute most of the remainder of the abundant sp The "other" species in Table 3.6 are primarily pennate species whic prefer benthic habitats. Benthic species are especially numerous at stations 60, 50 (core and dredge) and 22.

Station 60 is quite different from all the others, and frustu were scarcer than at any other station. Especially noteworthy is th scarcity of *Melosira* spp. The low abundance of *Melosira* and diatoms general in region 6 supports the 1972 phytoplankton data. The dredge sa from station 50 was also deficient in Melosira; but the nearly total dominance by Fragilaria pinnata, usually a benthic species, suggests that this sample was aberrant perhaps being overly influenced by a nearby littoral habitat. The surficial sediment from the core from this same area had numerous Melosira frustules, and phytoplankton samples during 1972 indicate that this should be the expected composition of microfossil assemblages. The surficial assemblage of the station 50 core is strikin similar to that of station 22. Station 22 is off the Churchill River plume (Patalas, 1974) and may be strongly influenced by local drainage as station 50 is. At these two stations Melosira spp. constitute less than 50% of the total assemblage while Fragilaria spp. are the second most abundant taxa, nearly 20% in both. However, station 58, which receives water only from the Muskwesi River, has 64% Melosira spp. demonstrating that water of entirely local Shield origin can support Melosira populations.

In summary there is very good agreement between the relative speci composition of diatom microfossil assemblages and the diatoms enumerated in the 1972 survey. This suggests that 1972 was not an aberrant year for phytoplankton populations and generalizations based on one year's data shoul not be overly misleading. In turn the correspondence between diatom populations observed growing in the lake and those found preserved in surficial sediments demonstrates the depositional and early diagenetic processes are not excessively distorting the fossil record. Therefore examination of sediment cores for diatom microfossils would be a reasonabl means of studying past diatom communities and past phytoplanktonic productivity.

3.7. SEDIMENT CORES AND RECENT LAKE HISTORY

In March 1973 three sediment cores were retrieved from Sout Indian Lake, one each from stations 10, 40, and 50. The location these cores is advantageous for showing the influence of the Churc River on these sites through time. Station 10 being closest to th Churchill inflow should be most significantly affected while stati is more remote and station 50 has no direct exchange with the Chur River plume. The station 10 core was 35 cm long, the station 40 c 71 cm, and the core from station 50 was 24 cm long. These cores a complete sedimentary sections as the lengths are limited by the co process (one m maximum) and sampler performance. All were visuall being grey in color with a soft "doughy" consistency. The station 50 cores had a thin layer (about 1 mm) of golden brown material on surface, but below this their color was a homogeneous grey. Stati differed in having a noticeably rusty brown color extending over t 7 cm gradually intergrading with the homogeneous grey sediment bel Although the cores were visually similar, it has already been ment that the sediments from the top of the station 10 core are somewha coarser (silty-clay) than the sediments from station 50 or 40 (fin All the cores were analyzed mineralogically, chemically, and paleo for the parameters previously discussed. Samples from the top and of each core were mineralogically similar indicating that there ha been any significant change in the types of detrital material bein contributed to the basin over the time period of record. Diatom m were very scarce below the top few cm of sediment in the cores from station 10 and station 50. Those frustules which are encountered appear to be poorly preserved either being broken or showing signs of dissolution. Poor preservation after deposition rather than recent colonization of these lake areas by diatoms is the best explanation for this stratigraphic distribution. Conditions required for good preservation of silicious microfossils are poorly understood (Lewin, 1961; Hecky et al., 1973) and it is quite probable that subtle differences in the geochemical environment of deposition between these cores account for the phenomenon. In the station 40 core diatoms were abundant throughout. The microfossil stratigraphy of this core will be discussed below.

3.7.1. The station 10 core:

As was noted earlier station 10 should be the most affected by the Churchill River inflow. Grain size analyses presented in Table 3.7 indicated that sediments from this station had a much greater proportion of silt than the other two, and this can probably be accounted for by this region of the lake acting as a settling basin for the coarser sediments carried in by the river. However, the concentrations of carbon, nitrogen, and phosphorus were not exceptional when surface sediment from the core was compared with other samples in the lake. The distribution of these elements with depth in the core is unexpected (Figure 3.4). The lowest concentration of organic carbon is found at the bottom of the core, 24 cm, and concentrations increase nearly monotonically from that depth up to the surface of the core. In total there is a 50% increase in the concentration of organic carbon trapped in the sediment. Such a relative increase is comparable to those that have been observed in lakes that have been culturally enriched (e.g. Bortleson and Lee 1972; Kemp et al. 1972). Carbonate-carbon, on the other hand, exhibits its highest concentration at the bottom of the core, and varies irregularly around 4-5 mg/g through the upper 20 cm of the core. Total nitrogen behaves similarly to organic carbon with a gradual increase from 3 mg/g at the base of the core to nearly 5 mg/g near the top. The single very high nitrogen concentration at 15 cm is unexplainable with the information available, but the general co-occurrence of the increases in organic carbon and nitrogen is demonstrated by the C:N ratio which is fairly stable.

Total phosphorus has its lowest concentration at the base of the core, 0.95 mg/g, from which it undergoes a gentle increase up to 1.4 mg/g at seven cm. Between six and seven cm there is a sharp increase to nearly 2 mg/g after which there is a rapid decline to approximately 1.6 mg/g at the surface. The overall correlation between total phosphorus and organic carbon is striking, both increase by nearly 50% from the base of the core to the surface, but correspondence in detail is lacking. This lack of direct correspondence is best observed in the C:P ratio which has a pronounced dip from three to seven cm where the maximum phosphorus concentrations occur. The conclusion reached earlier that much of the phosphorus is associated with mineral material is not contradicted by the behavior of carbon and phosphorus in this core. It is likely that an increase in detrital phosphorus would be accompanied by an increased availability of phosphate-phosphorus in the lake which could in turn lead to increased organic production in the overlying waters. The stability of the C:N ratio or at best the slight decline would seem to rule out a strictly terrigenous origin (high C:N) for the apparently increased carbon input. The conclusion that phosphorus loading has increased and concomitantly productivity has risen is necessarily based on the assumption that sedimentation rates and general sources of sediment at the coring site have remained rather constant. An alternative explanation involving a changing depositional environment while the lacustrine conditions remain the same seems less plausible especially when the core from station 40 is considered. However, the lack of absolute dating for these sediments and knowledge of sedimentation rates reduces the probability that can be attached to any interpretation especially in a lake with as complex a sedimentary environment as Southern Indian Lake.

3.7.2. The station 40 core:

Station 40 is near Missi Falls, the point of exit for the Churchill River from the lake. Grain size analysis of surficial sediments at this station revealed that the proportion of silt was only half that of station 10 indicating that sedimentation within the lake had removed substantial amounts of coarser material. The remote position of station 40 with respect to the inlet should mean that relative to station 10 it is less influenced by the suspended load of the inflowing Churchill River. The average C:N and C:P ratios (Figure 3.4) are lower and higher respectively than in the station 10 core. C:N ratios below five are common while the C:P ratio is generally well above 50. These ratios, under explanations given previously, should mean that station 40 sediments are relatively less derived from detrital mineral material and allochthonous organic material than station 10, and this would be consistent with expectation. The core is nearly three times as long as the station 10 core and a longer chronological record might be expected. Starting from the top of the core basic similarity with the station 10 core can be discerned. Organic carbon decreases from high values of nearly 30 mg/g at the surface down to less than 20 mg/g at 13 cm depth, a decrease of approximately 50% which is comparable to that observed at station 10. Total nitrogen has by far its highest concentrations at the core's surface with a rapid decline to four cm, below which a slight decline extends down below 10 cm depth. The resulting C:N ratio is much more variable than at station 10, and this phenomenon might be explained by varying ratios of allochthonous organic inputs to autochthonus production. Below 20 cm the C:N ratio is rather invariant at nearly five or less. These quite low ratios should indicate that most of the organic material incorporated in the sediments at that time was produced by phytoplankton in the lake. The higher values occurring above 15 cm should then indicate that inputs of allochthonous organic material have increased in the relatively recent past. The increase in organic carbon has been more nearly constant than the C:N ratio which should mean that autochthonous production has increased also. This is certainly true near the surface where very high organic carbon values are accompanied by high nitrogen and low C:N ratios.

Total phosphorus decreases from a high of 0.95 mg/g at the surface to 0.80 mg/g at 12 cm. This decrease is markedly less than occurs at station 10, but it is discernible and repeatable under the close sampling interval. Explanation for the reduced impact on phosphorus sedimentation at station 40 is probably found in the remoteness of this station from the Churchill inflow. If a sizable proportion of the total increased phosphorus input to the lake is carried in as silt-sized particles, then much of this would be sedimented in region 1 while relatively little would be transported as far as region 4. Silt-sized material would be relatively unweathered compared to the fine clay material, and it is probable that inclusions of phosphorus minerals would be found in this unweathered material. Little of this material has been carried as far as station 40, but increased loading of soluble phosphorus which would be expected to accompany this material could be transported to region 4 and beyond, granted the present low retention of phosphorus by the lake (Cleugh, 1974). This soluble phosphorus could have a positive effect on plankton production in this region. Higher organic carbon concentrations, higher C:P ratios, and lower C:N ratios would be the result, and this is observed. The difference in the response of the C:P ratio over this time period between station 40 and station 10 is especially demonstrative. At station 10 the C:P ratio underwent a conspicuous dip while at station 40 it increased markedly.

The occurrence of quite similar trends in several chemical parameters over comparable depth and time intervals at two widely separated stations should rule out the possibility that the changes in either of these can be attributed to changes in the environments of deposition. Rather these cores constitute evidence that basic environmental changes have occurred in the Churchill River drainage basin within the recent past (affects are noticeable up to the present). Population densities are too low and land use practices too primitive over most of the basin to invoke culturally induced enrichment by human wastes or agricultural fertilization (Churchill River Basin Task Force, 1973). Areas of maximum cultural impact, farming and logging, in Alberta and western Saskatchewan are in the most distant portions of the Churchill drainage; and it seems unlikely that these land disturbances would be traceable to Southern Indian Lake. The absence of detrital material from the Cretaceous shales in the southwestern portion of the Churchill basin was noted in the discussion of core mineralogy. The evidence, as circumstantial as it is, indicates a soil perturbation of some sort which has increased erosion within the basin and resulted in increased sediment and nutrient yield. Changing land use practices which would cause the soil perturbation is most likely attributable to the entry of European man and culture to the area. If this assumption is made then it is possible to estimate provisional sedimentation rates. This may be the only method, excepting radionuclide dating to establish a chronology for these cores as palynological studies on other cores from high latitude Canadian lakes indicate that there is no evidence for culturally induced changes in the relative pollen deposition (Mott, 1973). If 1870 is chosen as a reasonable date for the onset of significant increases in the European population of the Churchill basin and such a date is assigned to a depth of 14 cm in the station 40 core and 20 cm in the station 10 core sedimentation rates of 1.4 m and 2.0 m per thousand years can be calculated. These are not unreasonable rates for a lake with fairly high sediment loading. The relative magnitude of the rates at the two stations should be reasonably correct as the Churchill River is the overwhelming source of sediment to the lake and station 10 is closer to the mouth. Assuming that the rates are reasonably correct the base of the station 10 core should be approximately 175 years old while the base of the station 40 core should be nearly 500 years old. A sample from the bottom of the station 40 core has been submitted for radiocarbon analysis to verify the provisional rate. It is interesting to note that the peak of total phosphorus in the station 10 core would be assigned an age of 30 to 40 years under the proposed sedimentation rate. Such dates would nearly encompass most of the construction phase of power and storage dams on the Churchill River and its tributary, the Laurie River (Churchill River Basin Task Force, 1973).

Below 15 cm in the station 40 core organic carbon values are rather constant until substantial increases occur at 45 cm and more markedly at 50 cm, increasing the C:P ratio. At the latter depths total nitrogen also increases markedly lowering the C:N ratio. This carbon increase differs from the more recent one because total phosphorus does not increase at all. These changes in sedimentary C and N can be interpreted as being indicative of higher autochthonous production in the distant past (perhaps 500 years or more before the present). This increased productivity was not accompanied by increased soil erosion (increased detrital phosphorus) and a subtle climatic change might be invoked provisionally.

The station 40 core has fossil diatoms present throughout its length and this diatom stratigraphy tends to support the inference from chemical stratigraphy that the lake may have been as productive when the lowermost sediments were deposited as it is now after culturally induced disturbance. As figure 3.5 shows, from the sediment surface to a depth of 20 cm *Melosira islandica* is the most abundant of the *Melosira* species. From 30 cm to 50 cm *M. ambigua* constitutes nearly 50% of the total diatom assemblage. *Melosira ambigua* is generally found in more eutrophic waters than *M. islandica* (Lund, 1962), and this species shift can be explained by invoking more eutrophic conditions when the sediments at the base of the core were being deposited. Total numbers of frustules (relative numbe of frustules from a standard sediment volume and standard dilution) are also highest at the base of the core suggesting at least that the diatoms were more productive at that time. The possibility that the sedimentation rates of detrital material were lower cannot be overlooked, but higher productivity is consistent with all the lines of evidence available, i.e. organic carbon content, C:N ratio, C:P ratio, taxonomic composition of the fossil diatom flora, and number of diatom valves per unit of sediment volu

3.7.3. The station 50 core:

Region 5 is well off the Churchill River plume, and it should reflect events in its own local drainage which primarily is from the Wadd River and to a lesser extent the Muskwesi. The core from station 50 conta no clear indication of recent changes in productivity. Organic carbon is low, generally less than 0.5% through the upper 15 cm. Likewise total nitrogen is very low through this interval except for a distinct peak between 11 and 13 cm depth. From 17 to 19 cm both organic carbon and total nitrogen show a definite peak being higher by a factor of 4 than either preceding or succeeding values. The average C:N ratio is substantially lower than either the station 10 or 40 core, and this probably reflects the lower input of detrital organic materials to this lake region. Total phosphorus is nearly constant throughout the length of the core and the values are comparable to the deeper sediments in the station 40 core. Because of the lack of any evidence for modern changes in basin productivity it is not possible to correlate any depth of this core with the other cores with any certainty. Because of the very low rate of water renewal and consequent sediment loading in this area, a much lower average sedimentation rate for the region would be expected. If the rate were approximately one-half that of station 40 the distinct maximum in organic carbon and nitrogen near the base of the station 50 core might be correlated with the high carbon and nitrogen at the base of the station 40 core, and a causation unrelated to events in the Churchill basin alone could be invoked for the higher productivity at that time. However, the extreme local variability in sedimentation rates mentioned earlier, makes the assumptions required for this tentative correlation seem very tenuous. The recent changes in organic sedimentation at stations 10 and 40 can be attributed to disturbances within the Churchill River basin with greater certainty. Region 5 as represented by the core from station 50 has not been noticeably affected by these changes, and this supports the view reached in other reports of the Fisheries-Limnology Study (Cleugh, 1974; Patalas, 1974; Hamilton,1974) that this area receives very little water of Churchill River origin.

3.8. RECENT SEDIMENTATION - CONCLUSIONS

Examination of surficial sediments from Southern Indian Lake indicates that it is a very complex sedimentary basin. Bottom topograp and exposure to wind appear to be the dominant factors controlling sediment distribution over much of the lake while hydrographic slope currents are significant in channel constrictions. Because of these factors there is no simple relationship between grain size and depth as is often observed in lakes with morphometrically simple basins. The presence of ferromanganese nodules at several deep stations support the view that some of the deepest areas of the lake have very low to neglig sedimentation rates while core analyses suggest that other deep areas m have rates between one and two m per thousand years. The control of sediment deposition by often very localized conditions renders predicti about the fate of any particular sediment source very difficult especia if the basin morphometry and circulation patterns are altered at the sa time.

Certain broad patterns of sedimentation can be recognized despit the heterogeneity of the depositional environment. Much of the sand an silt contributed by the Churchill River appears to be deposited soon af entry to the lake while smaller proportions of the total clay brought in is retained. The clarification of the waters (decreased turbidity a increased Secchi disc) during passage between region 1 and region 4 als demonstrates this (Hecky *et al.*, 1974). Inshore shallow areas are usua depositional environments for fine sediments because the complex shorel produces many protected bays. Offshore areas may be sites of depositio or non-deposition depending on: 1) the relationship between depth of t site and the local wave-base; 2) the fetch length and bearing of prevai winds which produce littoral drift; and 3) the channel cross-section an its effect on the velocity of the hydrographic slope current.

Analysis and interpretation of sediment cores from Southern India Lake indicate recent disturbances in the Churchill River basin which see to have mobilized phosphorus, largely in particulate form, and caused so increase in the amount of organic material incorporated in portions of the lake affected by the Churchill River. The densest human populations and most intensive land use in the basin are in the southwestern reaches far removed from Southern Indian Lake. Circumstantial evidence suggests that much of the mobilized phosphorus is in silt-sized particles which would seem to require a more local source in order for it to be transpor to the lake. Soil perturbations associated with land use practices of European man are a possible explanation while a pronounced peak in total phosphorus at station 10 might correlate with the construction of hydro-electric dams upstream in the basin. There is also evidence from the longest core that there were prehistoric changes in lake productivity, bu these earlier changes don't appear to involve any noticeable increases i total phosphorus. The core from station 50 which is unaffected by the Churchill River does not exhibit any modern changes in productivity or total phosphorus incorporation which suggests that the disturbance is localized in the Churchill basin.

3.9. IMPLICATIONS OF FLOODING AND DIVERSION

The impoundment of Southern Indian Lake and diversion of t Churchill River flow will have profound effects on the sedimentat budget and sedimentation processes in the lake. A new source of will become available and existing sediment inputs will be redire These alternations in sedimentation could have profound effects o biota of the lake. The Physical Impact component of the Lake Wi Churchill and Nelson Rivers Study has undertaken the classificati new shoreline by constituent materials, i.e. rock, sand, clay, o moisture content as indicated by vegetation, and thickness of ov (John Parry, personal communication). The classification is br on that of Newbury et al. (1973). A generalized evolutionary de and time scale is also being constructed for each shoreline type the experience of numerous other reservoirs in Canada. The Phys study, however, is not considering the eventual distribution of released sediment or its possible effect on water quality. This will attempt to address these problems based on the scanty infor presented on present sedimentation processes in the lake. In or this several, unsatisfying but necessary, simplifying assumption made. First of all, from the numerous shoreline types described Southern Indian Lake the types most likely to produce abundant a new sediments must be identified. Secondly, assumptions about d must be made, i.e. whether the released sediment will have an af a broad area or only locally. Thirdly, assumptions about the ti of release, i.e. delay before significant release occurs and duratio significant releases after initiation. The shoreline types are discu below in relation to these necessary assumptions, and conclusions are given in Table 3.7.

The first class of shoreline to be considered is that which is primarily under bedrock control. This shoreline can vary from steep bedrock cliffs with no overburden to rather gently sloping banks with overburden beach. In all cases the shoreline shape is determined by topography of the exposed or underlying bedrock. Four basic types of this shoreline are prominent on Southern Indian Lake. Type 11 is a s bedrock with sparse overburden. A raised water contact on this shore does not result in any significant release of sediments. The next thi types, 13, 14, and 15 are generally associated. They may be considere as having started from a similar morphology, and their evolution was primarily determined by the degree of exposure to wave action. The ty 13 is generally found at exposed headlands which are interspersed by t 14 and 15 in more protected areas (Newbury _et_ _al_., 1973). Because of exposure to wave action, type 13 generally has a rather wide, wave-was rocky beach while type 15 has bedrock exposed only narrowly at the wat edge. Its backshore slope tends to be greater than that of 13, but mu less than 11. Type 14, as opposed to the other types, has a beach mad overburden materials, clay or sand.

In terms of probable sediment production and affect on water qu the following evaluations are made. All these shorelines have varying thicknesses of overburden, primarily glaciolacustrine clays, on the ba

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and permafrost where the organic overburden is sufficiently thi
fore, the potential release of sediments from all of them is la
the new shoreline is established. Dispersion of the released s
could vary appreciably. If wave action is sufficient to disper
overburden into discrete clay particles (less than two micromet
diameter) the particles could be carried great distances and a
proportion may be transported out of the basin. By this proces
1), turbidity and light extinction could be increased over larg
leading to reduced algal productivity (Hecky et al., 1974). Un
efficient wave action, silt-sized clay aggregates may be produc
would settle relatively rapidly in quiet environments (process
this occurs, turbidity would only be affected locally; but silt
burial of benthos and spawning sites would be a greater problem.
the present shoreline typology of bedrock controlled areas is a
of exposure and headlands are likely to be headlands after inund
shoreline types will differ in dispersion. The type 13 shoreli
most exposed, will follow process 1, while types 14 and 15 will
follow process 2 to a relatively greater extent. Fine clay-size
will also be produced by types 14 and 15, and therefore these sh
will affect turbidity over a wider area but to a lesser extent t

The three bedrock shorelines will also differ markedly as
time scale of shoreline evolution. Standing trees are the singl
determinant of timing (R. Newbury and J. Parry, personal communi
While the trees stand, they serve as an effective breakwater to
waves and greatly retard erosion at the new land-water contact.

trees are removed, erosion of the clay overburden can proceed rapidly. Trees die quickly when their roots are flooded, but removal is largely a mechanical process. Type 13, the headland shoreline, because of the greater wave energy of these sites will have the trees removed more rapidly than the protected sites; and this type will begin to affect water quality and sedimentation well before the others. Tree removal in protected areas can be greatly prolonged. It is not uncommon to find abundant standing, dead trees in reservoirs up to 40 years in age. Because of the somewhat greater slope of type 15 erosion may be somewhat more rapid than type 14 because of slumping.

Shorelines of alluvium or overburden are the second broad classification of types. Generally speaking this type of shoreline poses fewer problems under inundation than the bedrock controlled shoreline because the constituent material is coarser and the slopes are very gentle. The 22 shoreline is an exception to the slope generalization as this is the shoreline formed in thick deposits of ice-contact material such as eskers and kames. Raised water levels will mobilize large quantities of material as they are easily eroded, but the coarse grain size will limit distribution because sedimentation will be rapid. Type 27 is generically related to 22, but is found where deposits are thinner. The lower slope of type 27 will result in smaller release. Equilibrium will be established at a slower pace than 22 as slumping will not be prominent. Again the coarse grain size will limit dispersal. Type 24, the low alluvial shoreline, is typically found at the mouths of small tributaries. The coarse grain size and low slope will greatly limit the impact of inundation.

The remaining types of alluvial or overburden shoreline may be more notable for the release of rather large quantities of organic debris relative to the other types. These shorelines have low slopes and poor drainage which favor the accumulation of organic materials. Type 26, the treed muskeg, has a thick peat sequence at the surface, often outcropping on the typically steep backshore bank. Because of the thick organic cover permafrost is common. Water contact with the backshore bank will lead to slumping, and this shoreline could recede rapidly. The generally protected position of this type of shoreline will retard the process somewhat. The relatively low density of the organic material released could favor widespread dispersal. Organic overburden is less developed on the type 28, low willowed shoreline, but permafrost is still common. As with type 26, dispersal of organic materials could be substantial; but the low slope and protected position will reduce the impact.

The last shoreline,type 31, is almost entirely organic. A wide water saturated beach of black, organic mud leading up to a low ridge (less than two feet above the lake level, Newbury _et al._, 1973), protects a floating fen of saturated peat which can be extensive. Inundation of this shoreline could erode the ridge and/or raise the level of the peat and allow dispersal of the accumulated peat. This process gives rise to the floating islands which are so common in recently inundated northern reservoirs. The material can float until wave action breaks up the material to small constituent particles which waterlog and sink. The material can be transported great distances, and it can be hazardous for navigation. As with all large floating debris, it can also disrupt the activities of the commercial fisherman. This material is highly erodible and easily transported so that release should be rapid, but it will not persist over the time periods of the other shorelines.

In summary, the shoreline types vary markedly in their probable impact. A combination of factors indicate that type 13 has the greatest potential for sediment yield affecting a large area. Its effects are likely to be more immediate than the others, but consequently the effects will be more short term. A long-term release will result from types 14 and 15, but on the whole the effects of the long-term release will be more localized. Alluvial shorelines are largely found around present areas of deposition. Coarse materials and low slope reduce the potential for widespread impact from these areas. Fen shorelines are potentially quite troublesome. Table 3.7 summarizes the above arguments and rates each shoreline type as to potential detrimental effects from a given type. This relative potential is estimated from the ubiquity of effects (local or widespread) and the number of system functions likely to be significantly affected. Absolute effects will be determined by the lengths and areas of shoreline of a given type inundated. These are discussed by each lake region in the next section.

3.10. IMPACT BY REGION

At the time of preparation of this report, the Physical Impact component had not completed their study on Southern Indian Lake. Shorelines of regions 0, 3, 4, 5, and 7, as designated by the Fisheries-Limnology component, had been provisionally classified, and we were given access to these maps. Impact in these areas can be discussed in some detail, but the remaining regions, 1, 2, and 6 will be discussed more generally and subjectively. Final figures for lengths of each shoreline type will come from the Physical Impact Study. The relative estimates are used here which in view of all the uncertainties accompanying this analysis will be adequate.

3.10.1. Region 0 - Opachuanau Lake:

This region is nearly entirely a type 13 shoreline with type 11 and 14 of secondary importance. Impact should be rapid and could be extreme depending on the amount of overburden in the area. After region 7, this area appears to have the highest proportion of type 11 on the lake which should indicate that slopes are generally steeper than for the remainder of the lake. Consequently overburden should be somewhat thinner, and shoreline stabilization will be somewhat hastened. Projected plans for fairly intensive recreational use of this area have prompted proposals to Manitoba Hydro for extensive timber clearing in the area. This will also hasten shoreline stabilization. Rapid flushing by the Churchill and Barrington Rivers will remove much of the eroded material from this basin, and siltation will be consequently ameliorated as will turbidity. Overall the potential impact should be moderate and stabilization rapid compared to other areas of Southern Indian Lake.

3.10.2. Region 7:

Region 7 is predominantly a type 11 shoreline with type 13 secondary. Waterways in the area are quite narrow and, therefore, highly protected. Release from the type 13 shoreline will be slower than in the main lake. The high proportion of type 11 suggests that impact will be minimal in this area. Low flushing and great depths relative to surface area guarantee that much of the suspended material will remain in region 7.

3.10.3. Region 5:

Region 5 has the most complex shoreline of any area of the lake. There are extensive lengths of alluvial and overburden shorelines in this region because of the intersection of the water surface with a large esker complex, which affords an abundant source of coarse sediment. In the open water portions of the region, types 14 and 15 appear to be most prominent while lengths of 13 and 22+24 are about equivalent. Rapid mobilization of the coarse overburden can be expected but dispersion will be local. The types 14 and 15 will undergo slow release, but again local impacts will be greater. The relatively low amounts of type 13, the most critical shoreline implies that overall impact should be moderate from eroded mineral material. Along the lower reaches of the Waddie and Muskwesi Rivers which flow into this region there are extensive lengths and areas of treed muskeg, type 26. The shorelines of this region will be more productive of organic debris than any other region of the lake. This will increase the severity of impact in the years immediately following flooding, and it will spoil the sandy beaches so characteristic of this region. Water exchange between region 5 and the main lake has been shown to be poor in other sections of this report (Cleugh, 1974; Patalas, 1974, Hamilton, 1974). Consequently much of this debris will accumulate and settle within this region. Clearing of the lower reaches of these rivers as recommended by the Fisheries-Limnology component to Manitoba Hydro will ameliorate this somewhat as well as help to insure the success of the walleye spawning run and improve navigability. Severity of impact on this region would be of even greater concern if the area were presently being used by the commercial fishery as the organic debris would be a serious problem to net handling and navigation. The large potential release of floating debris from this area suggests that the feasibility of a boom across the channel into region 5 be considered. Such a boom could capture and eliminate floating debris and prevent its entry into the main fishing area of the lake (region 4).

3.10.4. Regions 3 and 4:

Regions 3 and 4 are discussed together because of the similarity of shorelines in these areas and the reduced flow of water these two regions will suffer under diversion. In both regions type 13 is by far the most abundant shoreline. Expected release of suspended materials is the greatest for any area of the lake in absolute terms, and the sediments should be widely dispersed. Under diversion, with greatly increased residence times, most of the eroded material will be retained within these regions. However, these regions will be losing a major source of sediments with the diversion of the river so that overall sedimentation rates may not increase. The suspended material lost to diversion is primarily fine-grained clay as coarser material settles out in regions 1 and 2 under the present regime, but the material gained from shoreline erosion will have a large sand and silt component. Consequently, nearshore sedimentation will increase, and it is siltation of these nearshore spawning grounds and benthic habitats which are of particular concern (Weagle and Baxter, 1973). Increased turbidity which could lead to a reduction in primary production (Hecky *et al.*, 1974) is more difficult to predict. Loss of the turbid Churchill River water could lead to reduced loading of suspended sediments, and the increased residence times will allow more time for sedimentation of contributed particles. Increased light penetration might result offshore in these regions, but nearshore littoral primary production will certainly be reduced to the probable detriment of small forage fishes. Whether or not this decreased production would be a problem to commercially important fishes higher up the food chain is difficult to forecast. The identification of region 4 as the most important whitefish spawning habitat in the lake and the probable detrimental affect of increased nearshore sedimentation on spawning success (Weagle & Baxter, 1973) indicate that these lake regions will be the most severely affected by shoreline stabilization. The several years to centuries required for the formation of new shorelines suggests that whitefish production may be depressed well into the future.

3.10.5. Regions 1 and 2:

Provisional shoreline classification for regions 1 and 2 was not available at the time of preparation of this report, but people involved with classification report that these regions are more similar to region 0 (Opachuanau Lake) than to regions 3 and 4 (personal communication, R. Newbury). Type 11 shoreline is more common, but type 13 is still most abundant. Erosive activity will be substantial. The question of whether the increased sediment loading from shorelines will be quantitatively sufficient to cause offshore increases in turbidity is difficult to predict. These offshore areas are quite turbid now because of the high inputs from the Churchill River, and maintenance of flow through these areas will continue after diversion. Grain size analyses indicate that this area now retains a large fraction of the coarser silt-sized material contributed by the river. The coarser material from shoreline erosion will also be deposited here. Increased inshore turbidity and siltation causing all the negative effects discussed previously can be predicted with greater certainty; but by and large, impact will be less severe in this area than in regions 3 and 4.

3.10.6. Region 6:

Provisional shoreline classification for this area was also not available at the time this report was written, but the entire area appears to be type 13, 14 and 15. Shoreline erosion is presently occurring in this area. Erosion in this case appears to be a natural continuation of the shoreline stabilization processes which set in after the last glaciation Extremely thick overburden and protection from prevailing winds has retarded attainment of a profile of equilibrium in several arm-like extensions off the southeastern corner of South Bay. Banks are often sufficiently steep for active slumping to occur. Sediment plumes continuously move out of these shallow bays and are dispersed over South Bay. The high turbidity and low light penetration (equivalent to regions 1 and 2) of region 6 can be attributed to this erosion. As the Churchill River does not presently affect water quality in this area and there are no other major inflows, transparency could be expected to be equal to or greater than that of region 5 if erosion weren't significant. That such is not the case reflects the impact that even a relatively small area of stabilizing shoreline can have on a relatively large body of water. The shallow mean depth of region 6 (Cleugh _et al._, 1974) contributes to the problem as much of the region is shallower than local wave base and constant resuspension of sediments can be achieved. Turbulent resuspension also allows dispersion into the individual fine clay particles which constitute the overburden. Inundation can be expected to greatly aggravate the stabilization processes in South Bay. Overburden is quite thick in much of this area and potentially large amounts of material could be mobilized. Deteriorating turbidity conditions can be foreseen, reducing the low production of the area even more. Diversion through South Bay could ameliorate these conditions somewhat as the water movement produces a greatly enlarged output from the system. The finer sized particles at least will be swept from the area. However, flow can also favor water mass formations as now occurs in the main lake. Lower interchange than might be hoped for could create highly turbid conditions in the southeastern part of the South Bay while the northwestern part takes on the characteristics of regions 1 and 2. Presently South Bay is the most unproductive region of Southern Indian Lake. This is likely to be true after diversion also. The thick overburden in this region guarantees that stabilization could take a very long time, even centuries as has bee required under the natural conditions.

3.11. SUMMARY

This section has attempted to amplify the Physical Impact study b identifying probable impacts and at least their qualitative significance to ecosystem aspects of particular interest to fisheries and limnology. Potential hazards of inundating particular shoreline types have been assessed in a non-quantitative manner as the available data preclude any other treatment. Consideration of the extent of a particular shoreline type in any region, its probable contribution to water quality changes an to sedimentation permits an attempt at prediction to be made. This assessment process has identified regions 3 and 4 as the most significantl affected. There, the co-occurrence of greatly increased nearshore sedimentation and extensive spawning grounds of whitefish create a critical situation. Zoobenthos, the primary food of whitefish, will also be negatively affected by nearshore siltation. Turbidity, which is at least in part limiting to primary production in Southern Indian Lake, may not deteriorate excessively in regions 3 and 4 as the sediment contribution of the Churchill River will be lost. In other regions of the lake reductions in primary productivity may occur during the shoreline stabilization process, as well as reduced zoobenthos production and spawning success because of siltation. The potential of region 5 for producing floating debris prompts the recommendation that booming of the Sand Point channel be considered to reduce the hazard of floating debris to fishing operations in region 4.

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Table 3.1. Sediment descriptions from the benthic survey, July 1972.
Asterisks indicate stations where nodules were found.

Station	Depth (m)	Sediment type (field descr
01*	7.5	Clay-round nodules
02	5.0	Grey ooze
03	4.5	Brown ooze
04	9.7	Grey ooze
05	8.0	rock
06	1.6	rock
10	17	
11	3.8	rock
16	21	Brown ooze
19	5	Brown ooze
20*	20	Brown ooze w/nodules
21	11	Brown ooze over coarse gravel
22	14	Muddy gravel
23	3.1	Grey-brown ooze
24*	19	Brown ooze with nodules
25	2.5	Brown ooze
30	20	Ooze-sand-gravel
31	16	Brown ooze
32	15	Grey-brown ooze
33	14	Grey-brown ooze
34	3.5	Grey ooze
35	3.7	
40	22	Ooze over gravel
41	15	Grey-brown ooze
42	18	Grey-brown ooze
43*	12	Sand 10% Gravel 15% Nodules
44	16	Gravel
45	6	Reddish brown ooze
46	23	Grey ooze
47	18	Grey-brown ooze
48	7.5	Brown ooze
50	11	Brown ooze
51	17	Brown ooze over grey clay
52	4.4	Brown ooze
53	2.6	Clay (grey)
54	3.7	Sand over clay
55	7.0	Sandy ooze
56	5.4	Grey ooze
57	12	Grey brown ooze
58	2	Brown clay weeds
60	8.1	Grey brown ooze
61	8.3	Brown ooze

Table 3.1 cont.

62	2.9	Grey-brown ooze
63*	2.3	Grey-brown ooze w/nodules
64	3.0	Grey-brown ooze
65	2.7	Grey-brown ooze
66	11	Grey ooze
71	14	Grey-brown ooze
72	9	Brown ooze
73*	8.5	Iron nodules
74	12	Grey-brown ooze
75	9.5	Grey-brown ooze
76	7.6	Grey-brown ooze
77	15	Grey-brown ooze
78	15	Grey-brown ooze

Table 3.2. Depth relationships of bottom types. Types are based on maximum particle size encountered in dredge sample.

Substratum	Samples	Range(m)	Mean
Rock	3	1.6-8.0	4.5
Gravel	7	8.5-22	15
Sand	2	3.7-7.0	5.4
Fine (Silt + Clay)	41	2-23	10
	52		

Table 3.3. Particle size distribution of surficial sediments from three cores recovered from Southern Indian Lake. Weight per cent loss to H_2O_2 pretreatment and weight percents of the three size fractions are given. The probable composition of clays is also indicated.

Station	10	40	50
H_2O_2	11.2	13.5	12.1
Sand	0.2	0.1	9.1
Silt	41.2	22.4	20.0
Clay	47.4	64.0	58.8
Illite	33.8	49.9	49.5
Chlorite	11.4	12.6	7.4
Montmorillonite	2.2	1.5	1.9

Table 3.4. Concentrations of organic carbon, carbonate-carbon, total nitrogen, and total phosphorus (all on a dry weight basis) in Southern Indian Lake sediments. Ratios are on a molar basis.

Station	Depth (m)	Organic-carbon (mg/g)	Carbonate-carbon (mg/g)	Total carbon (mg/g)	Total nitrogen (mg/g)	Total phosphorus (mg/g)	Org C:N (molar)	ΣC:N (molar)	ΣOrg C:P (molar)	ΣC:P (molar)
01	8	25.9	0.6	26.5	3.3	1.7	9.1	9.4	40	40
10	17	33.4	6.1	39.5	4.3	1.6	9.1	10.7	56	64
20	20	37.5	8.9	46.4	6.0	1.3	7.4	9.0	77	92
30	20	8.3	2.5	10.8	1.3	0.9	7.5	9.7	25	31
40	22	13.5	4.2	17.7	1.4	1.2	11.2	14.8	29	38
50	11	43.4	7.0	50.4	5.8	1.3	8.8	10.1	88	100
51	17	49.5	6.3	55.8	7.1	2.0	8.2	9.2	67	72
60	9	7.8	8.2	16.0	2.0	1.7	4.5	9.3	15	24
61	8	17.9	4.5	22.4	2.5	1.3	8.4	10.5	40	45
72	9	43.0	5.9	48.9	5.0	1.1	10.1	11.4	104	115

Table 3.5. Comparison of concentrations of C, N, and P (dry weight basis) in surficial sediments of cores (C) and Ekman dredges (E) from stations sampled in common.

Station	Organic Carbon (mg/g)	Carbonate Carbon (mg/g)	Total Nitrogen (mg/g)	Total Phosphorus (mg/g)	Org. C:N (molar)	Org. C:P (molar)
10 C	30.6	3.3	3.9	1.6	9.2	51
10 E	33.4	6.1	4.3	1.6	9.1	56
40 C	29.1	6.9	13.3	1.0	2.6	78
40 E	13.5	4.2	1.4	1.2	11.2	29
50 C	5.2	6.3	1.1	0.8	5.5	17
50 E	43.4	7.0	5.8	1.3	8.8	88

Table 3.6. Relative abundance (%) of diatom frustules in surficial sediments from Southern Indian Lake.
C = core surface. All other samples were taken with an Ekman dredge.
P = Present.

	10	10C	20	22	30	40	40C	58	50	50C	60
Centrales											
Cyclotella spp.	3	6	3	1	2	1	2	2	P	2	5
Melosira ambigua	8	P	4	3	2	3	15	4	P	3	-
M. granulata	5	10	10	-	3	4	16	4	-	1	1
M. islandica	32	4	42	40	44	71	36	52	P	37	9
M. italica	15	39	6	4	8	10	12	5	P	6	1
Melosira (Total)	60	53	62	47	59	83	72	64	1	47	12
Stephanodiscus spp.	15	11	14	8	12	8	4	8	P	5	4
Araphidineae											
Asterionella forniosa	5	13	6	4	3	2	6	2	P	6	-
Fragilaria spp.	7	7	5	20	13	1	4	12	77*	18	10
Tabellaria spp.	P	-	-	2	P	-	1	1	1	1	4
Other species	10	10	10	18	11	5	4	11	20	22	57

* Fragilaria pinnata 69%

Table 3.7. Principal shoreline types on Southern Indian Lake and their probable contribution to sedimentation and impact.

Class		Potential release	Dispersion	Timing	Primary target function	Potential severity
Bedrock controlled						
11	Steep bedrock	negligible	insignificant	not significant	not significant	nil
13	Low bedrock shoreline (wide wave-washed bedrock beach zone; backshore overburden thin to moderate)	slight to large	widespread	rapid	turbidity reduced primary production	great
14	Bedrock controlled shoreline with overburden beach	large	local to widespread	slow	turbidity and siltation; benthos and primary production and spawning	moderate to great
15	Low bedrock-controlled shoreline (narrow bedrock exposure beach often overhung by overburden; slope equal to or greater than 13)	large	local to widespread	slow to moderate	turbidity and siltation; benthos and primary production and spawning	moderate to great
Alluvium or overburden						
22	Shoreline in coarse sediments	very large	local	rapid	siltation; benthos production and spawning	slight
24	Low alluvial shoreline	light or moderate	local	rapid	siltation; benthos production and spawning	moderate
26	Treed muskeg	moderate	local to widespread	moderate	turbidity and siltation; benthos and primary production and spawning	great
27	Low shoreline in coarse sediments	light	local	moderate	siltation; benthos production and spawning	slight

Table 3.7. cont.

Class	Description	Potential release	Dispersion	Timing	Primary target function	Potential severity
28	Low willowed shoreline	light to moderate	local	great	siltation; benthos production and spawning	moderate
Organic						
31	Fen shoreline	moderate	local to widespread	rapid	turbidity and siltation; benthos and primary production and spawning	great

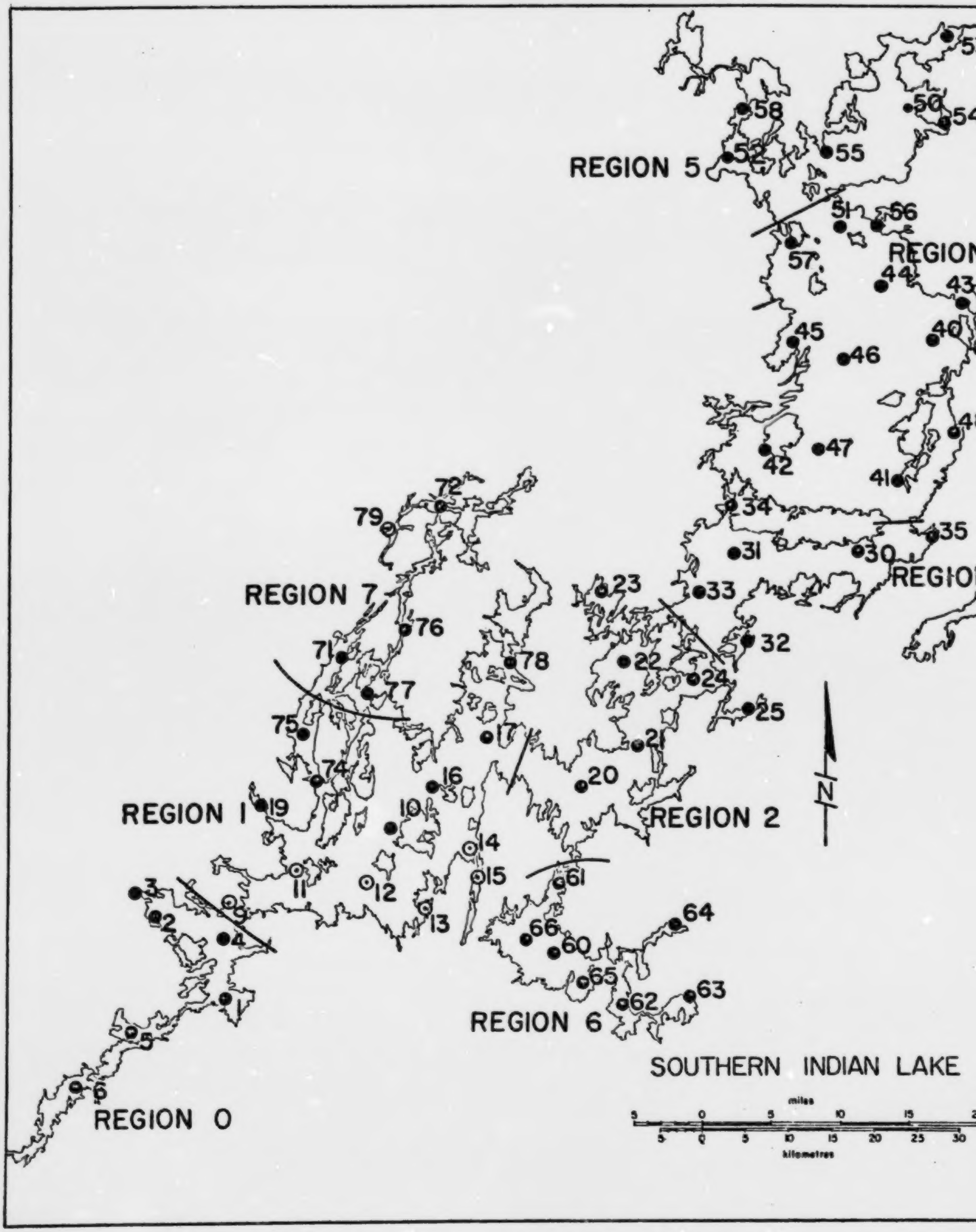

58
50
52
55
REGION 5
51
56
57
REGION
44
43
45
46
40
42
47
41
34
35
31
30
REGION
72
79
23
33
REGION 7
76
32
71
78
22
24
77
25
75
17
21
74
16
20
REGION 1
19
10
REGION 2
N
14
11
15
61
12
3
9
13
2
4
66
64
60
65
1
63
62
REGION 6
5
6
REGION O
SOUTHERN INDIAN LAKE
miles
5
0
5
10
15
kilometres
5
0
5
10
15
20
25
30

Figure 3.1. Sediment sampling locations of benthic survey.

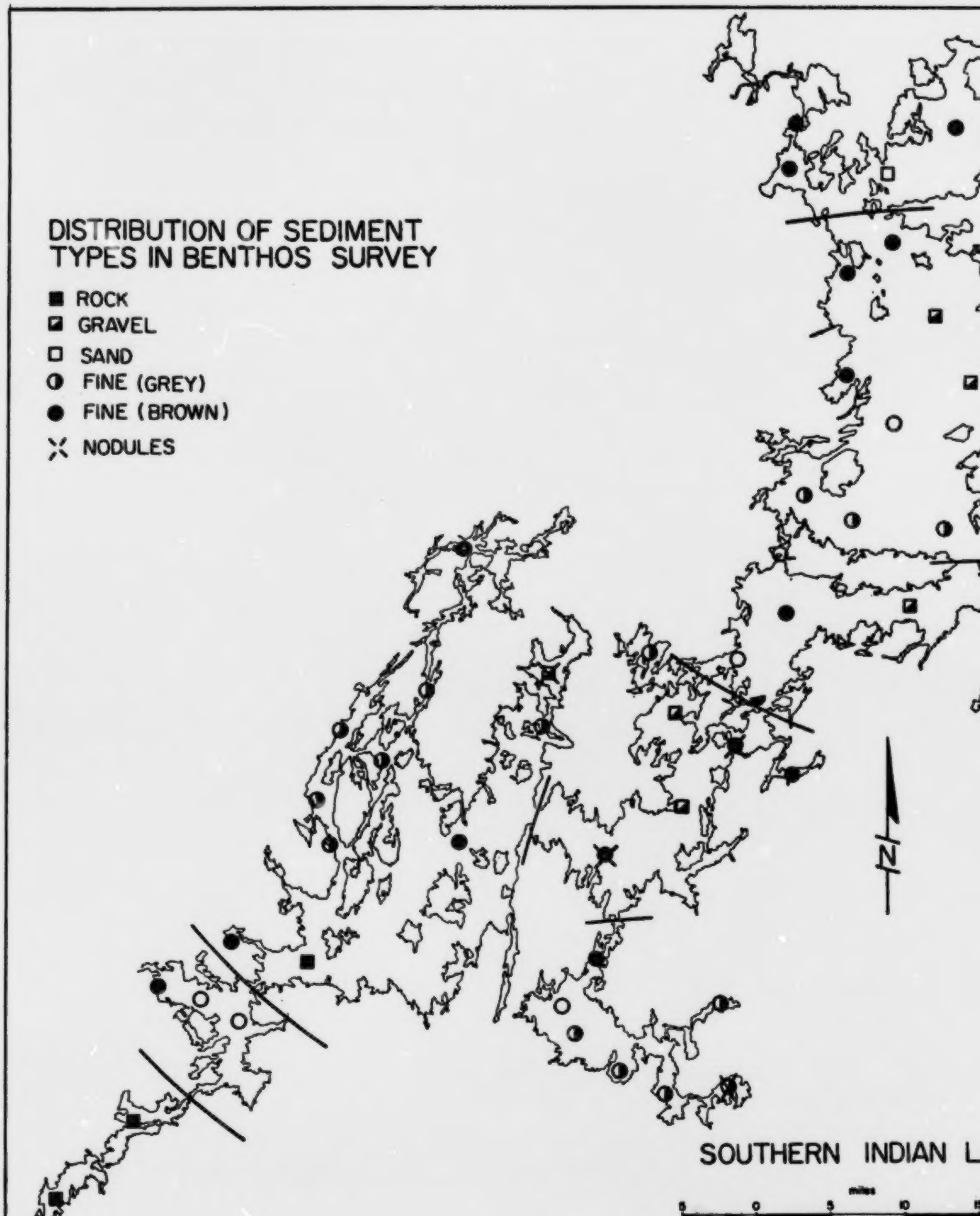
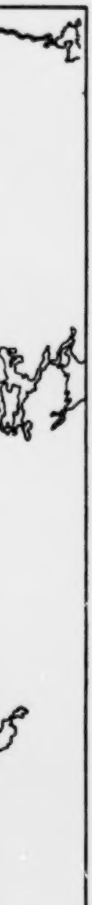

DISTRIBUTION OF SEDIMENT TYPES IN BENTHOS SURVEY
■ ROCK
◩ GRAVEL
□ SAND
◐ FINE (GREY)
● FINE (BROWN)
⁙ NODULES
N
SOUTHERN INDIAN L
miles
5 0 5 10 15
5 0 5 10 15 20
kilometres

Figure 3.2. Distribution of sediment types as indicated by benthic survey.



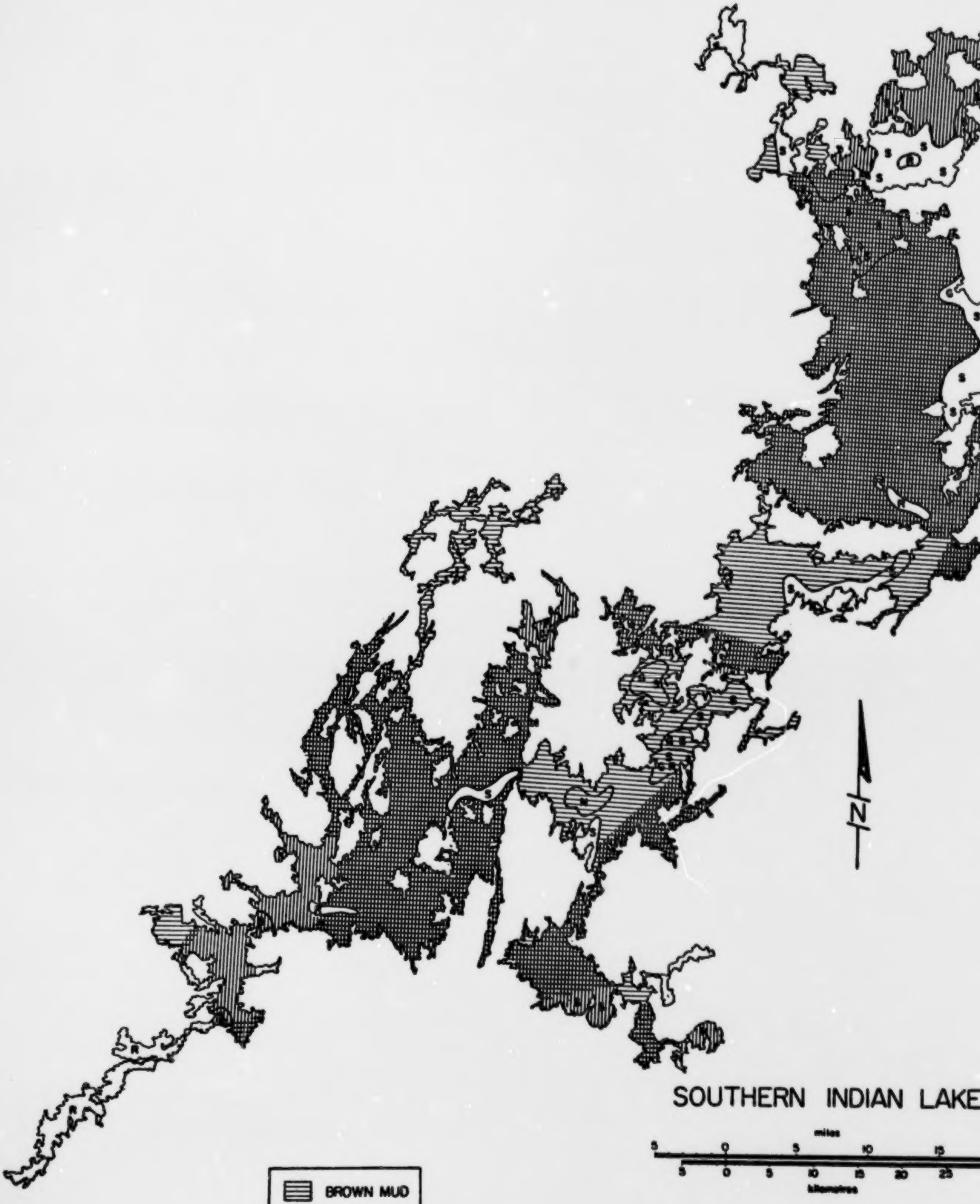
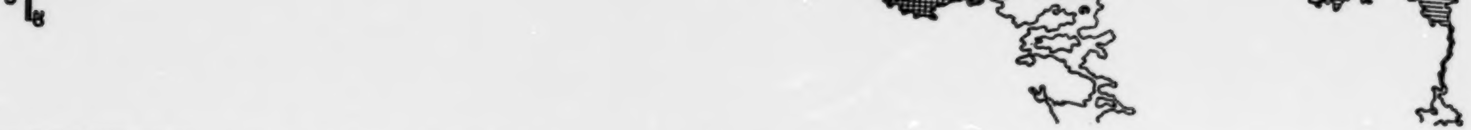
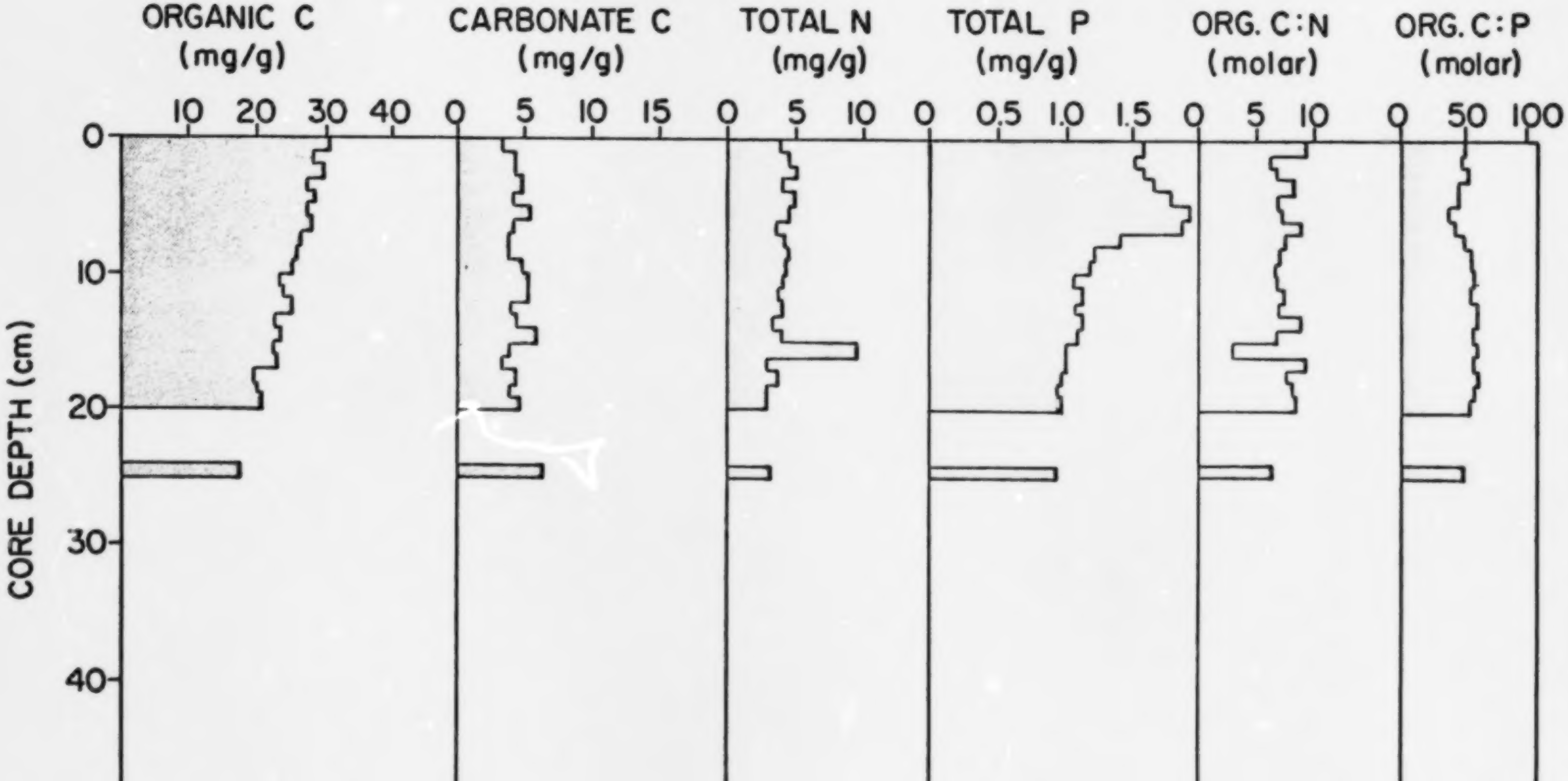

SOUTHERN INDIAN LAKE
miles
5
0
5
10
15
kilometres
5
0
5
10
15
20
25
N
▤ BROWN MUD
▥ GREY CLAY
S SAND
G GRAVEL
R ROCK
N NODULES

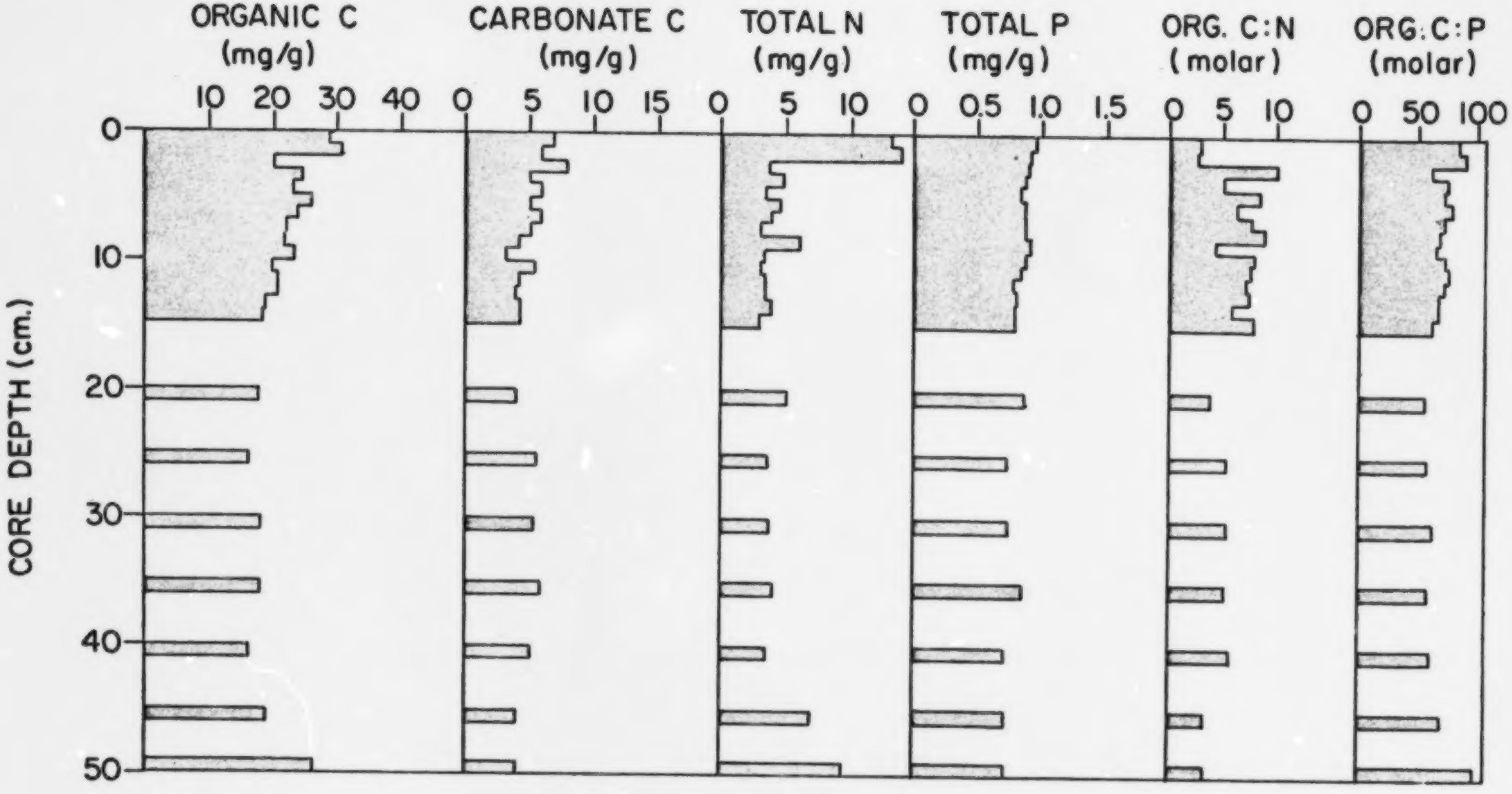
Figure 3.3. Generalized map of sediment type distribution.




ORGANIC C
(mg/g)
10 20 30 40
CARBONATE C
(mg/g)
0 5 10 15
TOTAL N
(mg/g)
0 5 10
TOTAL P
(mg/g)
0 0.5 1.0 1.5
ORG. C:N
(molar)
0 5 10
ORG. C:P
(molar)
0 50 100
CORE DEPTH (cm)
0
10
20
30
40

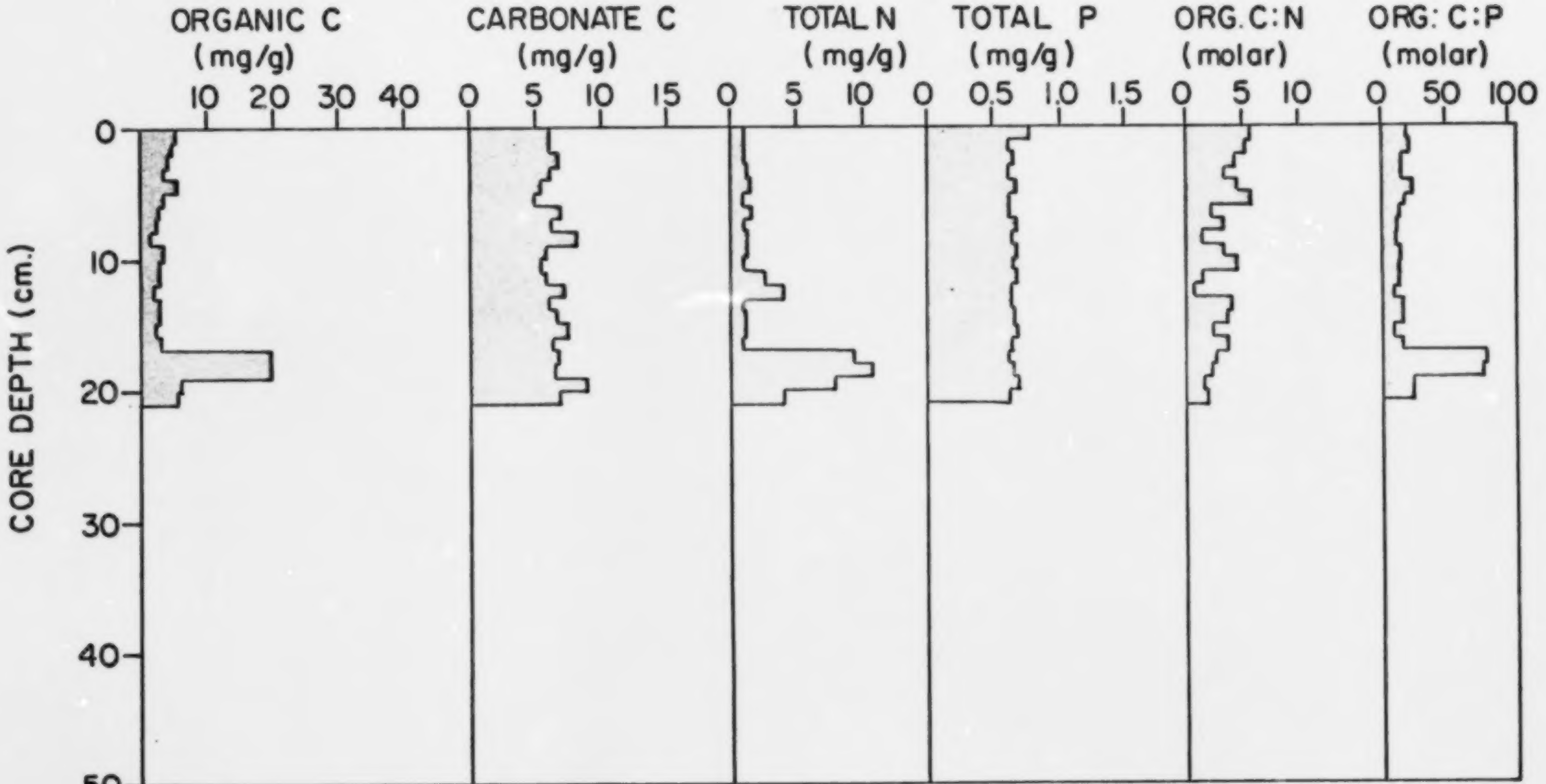
SOUTHERN INDIAN LAKE
STATION 10

Figure 3.4. Stratigraphy of carbon, nitrogen, and phosphorus in the station 10 core.



SOUTHERN INDIAN LAKE
STATION 40

Figure 3.5. Stratigraphy of carbon, nitrogen, and phosphorus in the station 40 core.



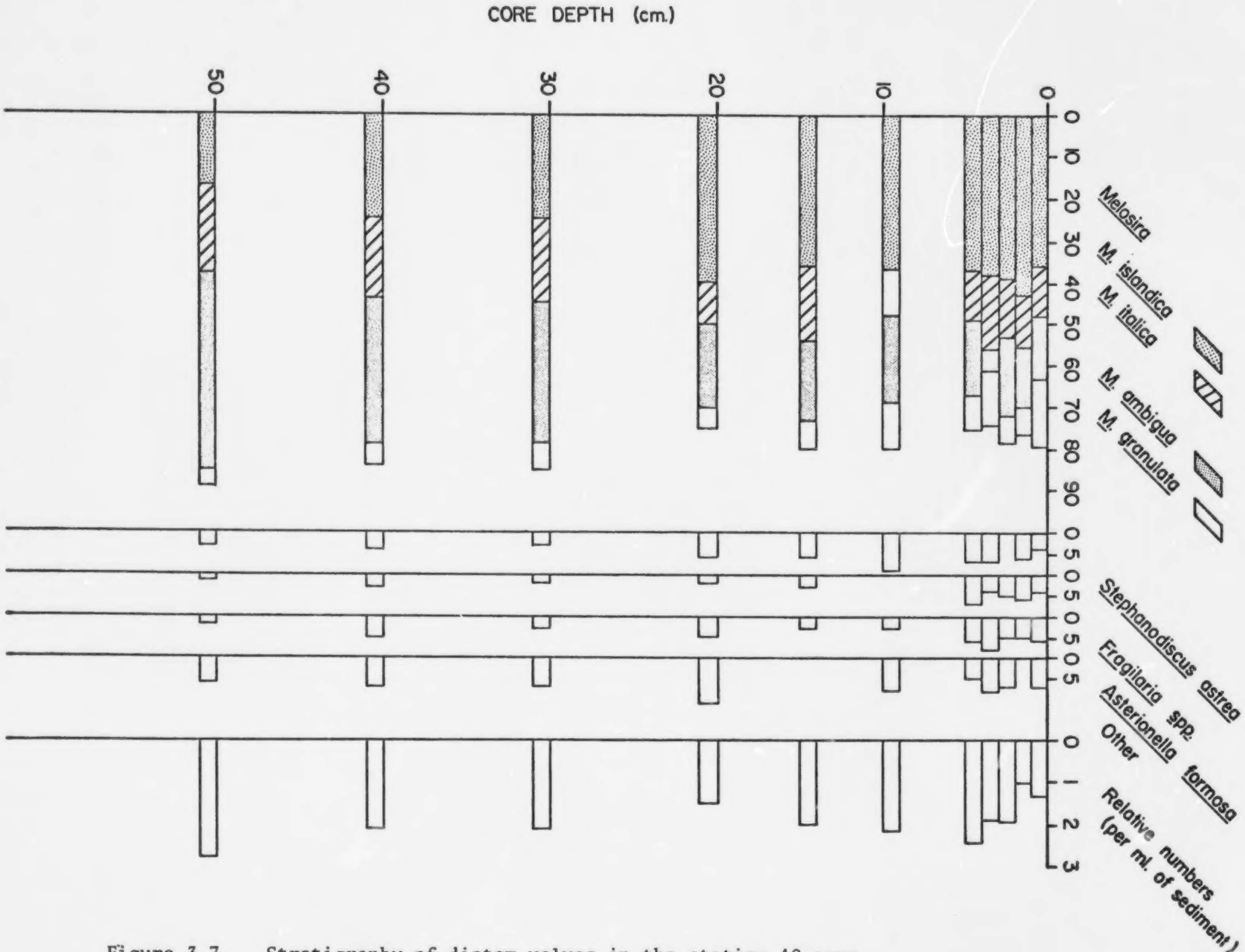


Figure 3.7. Stratigraphy of diatom valves in the station 40 core.

APPENDIX 5 - VOL. 1 - E.

PHYTOPLANKTON AND PRIMARY PRODUCTION IN SOUTHERN INDIAN LAKE

PHYTOPLANKTON AND PRIMARY PRODUCTION
IN SOUTHERN INDIAN LAKE

by

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Winnipeg, Manitoba
February, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

ABSTRACT

In 1972 the seasonal cycle of phytoplankton biomass in Southern Indian Lake exhibited two maxima. The first peak in standing crop followed ice-out in the spring when nutrient concentrations were high following winter recharge. The subsequent decline in standing crops resulted from declining nutrient concentrations and reduced turbulence. The second maximum occurred first in the upper lake and later in the lower lake. The second maximum is attributable to improved nutrient conditions caused by the influx of river water. The movement of this nutrient-rich river water throughout the lake accounts for the timing of the second maxima in different lake regions.

Maximum biomasses in 1972 and highest integral productivity in 1973 occurred in the lower lake (north of Long Point), the region of greatest light penetration. In regions not influenced by the Churchill River, e.g. north of Sand Point and in South Bay much lower biomasses and productivity were observed. Both of these areas have very low nutrient loading rates compared to the main lake regions and this probably accounts for the lower productivity. In South Bay light penetration is also a problem as bioassay experiments showed. Bioassay experiments indicated that phosphorus enrichment had a greater effect than nitrogen on natural populations, but algal growth and productivity under natural conditions were controlled as much by light as nutrients. In the upper lake and South Bay light was more of a problem while in the lower lake and north of Sand Point nutrients were more limiting.

Diversion will drastically alter productivity patterns in the lake as the high nutrient loading is redistributed. The lower portion of the lake, especially north of Long Point will decline to one-half to two-thirds its present productivity. Nutrients released from eroding shorelines after impoundment could retard this decline in the short term. Nutrient release in the upper lake will have little affect as light is more critical in these regions. Suspended materials from eroding shorelines will increase turbidity and reduce productivity near the new shoreline.

In order to prevent the productivity of the large lake area north of Long Point from declining to unacceptably low levels, it is recommended that a minimum annual discharge of 5,000 cfs at Missi Falls be guaranteed. The interim license allows minimum flows of 1,500 cfs in winter and 500 cfs in summer (or annual discharge of approximately 1,000 cfs). Operation under the latter conditions would drastically reduce the primary productivity of the lake with disastrous consequences for higher trophic levels.

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4.1. INTRODUCTION

Algal populations are the most significant primary produce large, aquatic systems. By utilizing light energy and nutrients initiate and sustain the trophic structure of the entire biologi community. Trophic transfers from the primary level to higher l can be complex and in general are not well understood, but the p production of a system is relatively amenable to estimation and broad constraints on the possible levels of secondary production zooplankton, zoobenthos and fish (Hall *et al.*, 1970). Algal pr may also secondarily effect the quality of fish stocks as well a quantity. Excess production not utilized by grazers and predato epilimnion of lake will be decomposed by bacteria with direct co to water quality. The crucial role which algae play in the comm metabolism of lakes, requires that their biomass, activity, and be adequately characterized in this study.

For Southern Indian Lake the following parameters have be during 1972-1973: estimation of phytoplankton biomass and taxon composition by season and by region, the ability of water from v locations in the lake to sustain growth of algae in culture, the identification of possible limiting nutrients for phytoplankton, estimates of rates of *in situ* phytoplanktonic production. The re these investigations, their interpretation, and their possible s for predicting probable ecological consequences of the planned i and diversion are presented in the following sections.

4.2. PHYTOPLANKTON

The phytoplankton consist of passively drifting algal species generally of microscopic size. Some groups are weakly motile and may be capable of actively changing their vertical position in calm waters, but none can significantly change their horizontal position within a water mass by self-motility. Therefore, phytoplankton species are tied to their containing water mass. The species present represent a time-integrated sample of those species which have recently been or are currently producing. The quantity and taxonomic composition can give insight into productive capacity of the water mass. Similarly, water masses may be discriminated by their contained phytoplankton populations, and lake areas of significant or negligible water exchange can be identified. These two applications, 1) productive capacity and 2) water mass discrimination, require two different sampling schemes. To evaluate the first, the main lake and river stations (09, 10, 20, 30, 40, 50, 60, 49b) established for chemical sampling (Cleugh, 1974) were sampled concurrently with the chemical sampling at three-week intervals. This allowed characterization of the spatio-temporal distribution of the algal populations in the central portions of the lake and permitted comparison with the acquired chemical data. In addition in late July a series of 55 samples were taken from 0.5 m depth over widely scattered areas of the lake: inshore, offshore, isolated bays, etc. These samples present an instantaneous picture of the distribution of algal biomass and species around the lake, and thus discrete water masses may be delimited.

4.2.1. The Southern Indian Lake flora:

The phytoplankton was identified and enumerated using the Utermohl (1958) technique (modified). Samples were preserved in Lugol's solution and an appropriate volume settled for enumeration. Biomass was estimated by multiplying the approximate volume of each cell by the number of cells per unit volume. A specific gravity of unity is assumed for the algae and the results are expressed as $mg \cdot m^{-3}$. The methodology is described in Vollenweider (1969). The method gives reasonably good preservation and it is usually possible to identify preserved material to the generic level. For species identification of many of the small,soft-bodied forms, live material is required. The species list in Appendix 4A was derived from live material.

Only three taxonomic groups (listed in order of importance), the Diatomeae, the Cyanophyta, and the Chrysophyceae achieve significant numbers at the main stations. The other groups, Chlorophyta, Euglenophyta, Cryptophyceae, and Peridineae are present, but always in very low numbers. These results for Southern Indian Lake can be compared with other lakes of the region which have been studied by similar techniques. Kling and Holmgren (1972) found the phytoplankton of the Experimental Lakes Area on the Precambrian Shield of western Ontario to be dominated by Chrysophyceae with the Cryptophyceae, Cyanophyta and Diatomeae occurring as subdominants. Lake Winnipeg (Holmgren and Kling, 1973) which lies on the boundary of the Precambrian Shield and the glacial drift of the prairies was found to have a complex flora with the large North and South basins dominated by Diatomeae and Cyanophyta (subdominants were Peridineae and

Chrysophyceae in the north and Chlorophyta in the south) while a narrow connecting region receiving predominantly Shield drainage grew mostly Chlorophyta, Chrysophyceae, and Cryptophyceae. To generalize from these studies, it might be possible to say that Shield waters tend to favor Chrysophyceae, Chlorophyta, and Cryptophyceae while being less favorable to Diatomeae and Cyanophyta. Cyanophyte "surface blooms" which are characteristic of eutrophic waters are rare in Shield lakes. Physiographically, Southern Indian Lake lies well within the Shield and it might be expected to exhibit a flora similar to other Shield lakes. Hydrologically, however, the lake receives nearly 90% of its water via the Churchill River which originates in the prairie regions far to the southwest; and it might be hypothesized that this prairie drainage and consequent nutrient loading may explain the different aspect of the flora.

The plankton of Churchill River lakes and large Shield lakes in Saskatchewan have been the subject of numerous studies extending over many years (Rawson, 1957, 1959, 1960a, 1960b; Koshinsky 1965), but the data are not directly comparable. The plankton was collected with nets in these previous studies. Nets create a bias towards the larger forms, and the species lists produced cannot be considered comprehensive. In general, these earlier studies show that Diatomeae and Cyanophyta are the predominant net phytoplankton in both Churchill River and Precambrian Shield lakes. Primary differences are quantitative, not qualitative, with higher total biomasses (dry weight of net plankton) and "blooms" of Anabaena and Aphanizomenon found in Churchill River lakes while lower biomasses (two to three times less) and only rare blooms occur in Shield lakes. As the methods of collection and standing crop estimations are quite different, it is not possible to compare biomasses absolutely, but Southern Indian Lake does experience small surface blooms of *Anabaena* and *Aphanizomenon* in August. This characteristic may attest to a relatively high nutrient loading which the Churchill River supplies. The apparent predominance of diatoms in large Shield lakes as well as Churchill River lakes suggests that turbulence as well as nutrients are involved. The large Shield lakes have an adequate wind fetch to allow effective wind mixing. In the larger river lakes wind would also be effective and in the smaller lakes the low residence times (two weeks or less) suggest that currents engendered by the hydrographic slope would generate significant turbulence which could maintain suspension of the negatively buoyant diatoms.

4.2.2. Spatio-temporal distribution of algal biomass:

4.2.2.1. Main stations:

For the purpose of this study, Southern Indian Lake is divided into seven major regions (Cleugh, Ayles, and Baxter, 1974) which are delimited by marked channel constrictions. Six main stations were established, one in each of the largest regions. Stations 10, 20, 30, and 40 lie along the axis of flow for Churchill River water. Stations 50 and 60 are different in their chemical characteristics (Cleugh, 1974) because they receive negligible portions of river-derived water. Depth-integrated estimates of biomass are given in Figure 4.1 and the partitioning of this biomass among the major taxa is also indicated. Also included in Figure 4.1

are seasonal values for Isset Lake, a nearby Shield lake, and the two rivers entering region 5, the Muskwesi and Waddie. These local Shield waters serve for comparison with the Churchill River and the regions of the lake receiving Churchill water. As Southern Indian Lake does not stratify, it is assumed that all algae suspended in the water, have the potential for reproduction (i.e. there is no thermocline to prevent the deep-lying algae from being reintroduced into the euphotic zone); and therefore, the biomass of the entire water column is integrated and the average standing crop is given in Figure 4.1.

All stations on the Churchill River plume attain biomass maxima equal to or greater than stations off the plume while average biomasses are always greater (Table 4.1). The biomass maximum at station 49b was due primarily to diatoms and this is true of maxima at all the stations with the exception of station 60. The values for biomass maxima increase along the direction of net water movement of the Churchill River plume, i.e. from station 10 through station 40, and this is also true for average seasonal biomass. This pattern is almost certainly flow-related and will be discussed later. Station 50, which receives only local Shield drainage, achieves a maximum of 1,600 $mg \cdot m^{-3}$ which is comparable to station 10 on the Churchill River plume. Station 60 (South Bay) has extremely low biomass despite the apparent presence of unused nutrients (section 4.3). Light extinction in South Bay is as high as any other area of the lake, and light limitation and low nutrient loading (section 4.7) probably explain the low productivity (discussed in section 4.4.3). The biomass minima for all stations occur in the winter under the heavy ice and snow cover (Cleugh

(1974) reports ice and snow thicknesses at several stations). These minima can be attributed to low light penetration reducing phytoplankton productivity. It can be seen in Figure 4.2 that winter standing crops are nearly equivalent all over the lake no matter what the water source. Only with the removal of physical limiting factors is the growth potential of the different waters visible. After ice-out stations on the Churchill River plume are more productive and this reflects high nutrient loading by the river (Cleugh, 1974).

The algal biomasses found in Southern Indian Lake (Table 4.1) can be compared with those found in Lake Winnipeg (Holmgren and Kling, 1973) for a regional comparison and the values given in Vollenweider (1968) for more general comparison. Maximum biomasses in Southern Indian Lake occurred in region 4 (3,000 to 4,400 $mg \cdot m^{-3}$). This region would be considered mesotrophic (3,000 to 5,000 $mg \cdot m^{-3}$) under Vollenweider's classification. The remainder of the lake would be considered oligotrophic to ultra-oligotrophic by the same biomass criteria. The average biomasses at each station are given in Table 4.1 and range from 1,130 to 1,950 $mg \cdot m^{-3}$ for the main lake stations on the Churchill River flow. This range is broadly similar to that observed in Lake Winnipeg in 1969. However, the maximum biomass observed in Lake Winnipeg was 10,000 $mg \cdot m^{-3}$ and there were several stations exceeding 3,000 $mg \cdot m^{-3}$. On the basis of algal biomasses alone Lake Winnipeg would appear to be somewhat more productive than Southern Indian Lake.

There is a very marked and regular periodicity in algal standing crops at each station. The Opachuanau Rapids station, 09, demonstrates a rather simple pattern which is probably characteristic of the Churchill River. Low values occur in the winter when growth rates are low because of low light. Algal biomass increases in the spring and declines in the fall in response to solar radiation. Such a simple cyclic pattern is probably characteristic of large, unpolluted rivers (Williams, 1972). The Waddie and Muskwesi Rivers by comparison exhibit much lower standing crops and a subdued periodicity. These small rivers may reflect seasonal periodicities of upstream lakes more than a river cycle. The upper lake stations, 10 and 20, exhibit a regular rise from an early spring low (Figure 4. a late August maxima and a steady decrease into the winter. At the first sampling date, station 10 has nearly twice the biomass of station 20 and the difference is due primarily to a significant population of the diatom genus *Melosira*. At station 30 the phytoplankton begin from low spring values and biomass increases at a slower rate than the upper lake stations with the largest biomass accumulation occurring at the end of the season. There is no sign of a decrease within our sampling period. Station 40 and 49b exhibit two biomass peaks, an early spring diatom maximum of *Melosira* spp. and a late summer maximum by the same genus. Station 50 exhibits a general periodicity similar to that of station 40; but, with the exception of the July 11 sampling, biomasses at 50 are significantly lower than at station 40, and the seasonal average biomass is lower than any of the stations receiving Churchill River water (Table 4.1).

Stations 40, 49b and 50 exhibit rather similar periodicities, i.e. two maxima per season despite their quite different water sources and chemical composition. This suggests a causation not directly related to nutrient source, and raises the question as to why similar early maxima were not observed at other stations. The early maxima at stations 40, 49b and 50 are due to *Melosira* spp. The species which are most prominent in Southern Indian Lake, *M. islandica* and *M. italica*, are known to perennate (survive on the lake bottom for long periods of time as viable vegetative cells). These species form large populations rapidly during isothermal mixing periods, usually late fall and early spring in north temperate lakes when there is sufficient turbulence to stir bottom sediments and resuspend cells (Lund, 1954, 1955, 1962). With rising water temperatures and decreasing turbulence, the cells quickly disappear from the water column even though no significant stratification may be present. Temperature increases at stations 40 and 50 lag significantly behind other lake stations (Cleugh, 1974) as they are in the last areas of the lake to ice-out. On the June 21 sampling, the other stations were at least 2°C warmer than stations 40 and 50. This difference in early season warming suggests that similar *Melosira* maxima may have occurred at other stations (excepting 60) prior to our initial sampling. An alternative explanation that *Melosira* does not perennate in other lake areas is not supported by examination of surface sediments from various areas. In these surface sediments, *Melosira islandica* is the dominant species at all stations with the exception of 50 and 60 (Hecky, 1974). Evidence for an early spring period of intense production at these stations is found by comparing the nutrient concentrations of the waters on March 31, 1972, under ice, and on June 21, given by Cleugh (1974). On March 31, total dissolved phosphorus was high all over the lake with 25-30 μg.l^{-1} at stations 10, 20, and 40, while on June 21, values are from 16-22 $\mu g.l^{-1}$. Similar reductio observed in nitrogen and silicon which is essential for diatom growth. March values for nitrate-nitrogen exceed 60 $\mu g.l^{-1}$ and silicon is approximately 1.5 $mg.l^{-1}$. By June 21, these concentrations are reduced to less than 5 $\mu g.l^{-1}$ nitrate-nitrogen and 0.3-0.8 $mg.l^{-1}$ Si. Intense production must have occurred after ice-out to cause these large nutrient reductions at all stations. Because of the pattern of ice melting and lake warming, these reductions would occur in the upper lake around the first of June and would occur later in the lower lake. Therefore, the late June sampling only observed the maxima in the lower lake.

The relative importance of the major taxonomic groups, Diatomeae, Cyanophyta, and Chrysophyceae, fluctuates in response to total biomass (Figure 4.1). Chrysophyceae are generally most significant in winter when total biomass (Figure 4.2) is low and their relative importance increases in the early July samples at stations 10, 40, and 50 where total biomasses are still declining from early season peaks. These increases in relative abundance are largely due to decreases in other taxa, although there is evidence for a real annual peak in standing crop of Chrysophyceae at this time (Figure 4.2). The maximum relative abundance of Cyanophyta varies in timing from station to station (Figure 4.1), but in terms of absolute biomass maxima (Figure 4.2) all stations with the exception of 60, exhibit August maxima. This late August peak was expressed as a weak surface bloom in regions 3 and 4. As the surface was not sampled, Figure 4.2 may underestimate the magnitude of the maxima. The diatoms after an early season peak (observed at 40, 49b, and 50, inferred at 10, 20 and 30) decline to low biomasses and then begin a steady increase through the summer with late summer maxima in the upper lake and fall maxima in the lower lake. The relative abundances of all the algae ar largely controlled by the waxing and waning of the Diatomeae.

Relatively few species account for most of the total biomass du periods of maximum growth as Figure 4.1 emphasizes. Melosira spp., predominantly M. islandica with M. italica of lesser importance, accou for almost all the diatom biomass. When combined with the blue-green genera Anabaena and Aphanizomenon, these species account for most of t annual standing crop in the lake. Other taxa, on the whole, appear t undergo negligible fluctuations in biomass. At stations 20 and 30 in early summer, the blue-green algal biomass appears to increase at a fa rate than the diatoms; whereas at stations 10 and 40, the opposite is On a relative basis, Anabaena and Aphanizomenon are never as importan 10 and 40 as they are at stations 20 and 30 (Figure 4.1 and 4.2). Suc pattern bears no apparent relation to the movement of Churchill River water through the lake, but it does correlate with the size of the bas (Cleugh, Ayles, and Baxter, 1974). Both region one (station 10) and region four (station 40) have well over twice the surface area of the other two regions. The regions are both wider and longer than the are around stations 20 and 30 which should permit better wind mixing becau of the greater fetch. Nutrient competition which is often cited to ex increases or decreases between these groups does not seem to be involv as the presence of large crops of one algal group does not prevent subsequent increases of the other group (Figure 4.2). The demonstrate importance of turbulence to the ecology of these Melosira species als supports the basin size hypothesis. The late summer diatom maxima at all stations may likewise be related to increased atmospheric turbule of the late summer and fall period, but we have no relevant data.

4.2.2.2. Horizontal distribution:

The seasonal algal standing crop data for the main stations dem that river influenced stations have higher biomasses than stations not influenced by the river. In turn, it becomes necessary to delimit the areas of the lake affected by river-derived water and to elucidate wat mass movements. Southern Indian Lake is a large lake with a complex, highly developed shoreline, and it receives inflow from diverse water types. These characteristics favor differentiation of water masses on both chemical and biological bases. Organisms will be sensitive to particular aspects of the water masses and as such, can serve as biolo "tracers". Their utility and interpretation is a function of their gr or reproductive rate. Phytoplankton with high potential growth rates will respond rapidly to subtle changes in their environment, but the changes and causality (nutrients, grazing, etc.) can be complex. Zooplankton with their slower reproductive cycles will be simpler to inte and they share with phytoplankton the desirable characteristic of passi movement. Benthic organisms as well as having longer life cycles, are not moved passively (under normal circumstances), and their distributi will reflect a time-integrated picture of the average position of wate types. The zooplankton and benthic fauna will be discussed in other reports (Patalas, 1974; Hamilton, 1974).

In July of 1972, 55 stations were sampled in Southern Indi Opachuanau Lake and the Churchill River in order to obtain a synop picture of phytoplankton distribution. Except for region 1 which sampled on July 30, all regions were sampled between July 1-16. samples were from 0.5 m depth and the preservation and enumeratio were the same as presented in section 4.2.1. As only one depth w the biomasses determined were not depth integrated, and they are directly comparable with the main station estimates which were in several depths. Therefore, the values given in this section for stations are the biomass values at 0.5 m and not the integrated f These single depth samples can reflect different patterns of alga stratification (shallow or deep maximum), which is turbulence rel well as the characteristic biomasses and algal composition of the water types. This extra distribution parameter renders these sam useful for water mass identification than integrated samples such vertical net tow used in the zooplankton studies. Despite these problems, the horizontal distribution of phytoplankton yields use information about the dynamics of the river-lake system.

Total biomass for the 55 samples is superimposed on the la surface in Figure 4.3. Highest values are found in the upper lak regions 1 and 7, and in the lower lake where the northern portion region 4 has the highest biomass found in the lake. In region 1, have total biomasses equivalent to or greater than that found in open waters while in regions 3, 4 and 5, the bays tend to have lo biomasses.

It is clear that, at least, inshore and offshore waters gener reflect differential growth of algal populations. Main station dat would indicate that in the northern end of the lake offshore popula are declining from early season maxima while in the south offshore populations are already into the early summer minima. In contrast populations decrease from south to north perhaps because of the dif in time of ice-out. A combination of these trends in inshore and o populations could produce the observed pattern. The algal groups composing the biomass of the bays is quite different from the open areas as will be discussed later.

Region 1 shows much higher biomasses than regions 2, 3, and 4, but this region was sampled two to three weeks after the others not directly comparable. As was seen in Figure 4.1, biomass at stat more than doubled during this period. On July 10 during the interva the remainder of the lake was sampled, station 10 had a biomass of 7 at 0.5 m which would still give this region a higher biomass than mo the lake and the river. Station 10 initiates its second biomass inc earlier than the downstream stations (Figure 4.1) and the synoptic p in July emphasizes this pattern. Region 1 is entering its second ma while region 4 is still declining from its spring peak. The high bi in the northern portion of region 4, it will be seen, is a lingering of the spring Melosira peak in this region. In general, this synopt picture of phytoplankton populations in July substantiates the impre that the main stations gave. Total biomass values are rather simila much of the open area of the lake, but the bays and backwaters are d

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Consideration of the individual algal groups also supports th
Cryptophyceae constitute a significant portion of the
Shield lakes at ELA in northwestern Ontario (Kling and Holmgr
but they are conspicuous by their absence from the main stati
Southern Indian Lake. Figure 4.4 shows that Cryptophyceae are
the lake, however, they are numerous only in the bays. They
prominent in region 7, and this distribution suggests that th
exchanges water only slowly with the main lake. The Chrysoph
(Figure 4.5) which are also prominent in the ELA lakes demons
similar pattern in the upper lake, but they are also found in
portions of the lower lake. As discussed above, the pattern
may not be comparable with the rest of the lake. On July 11 a
230 mg.m^{-3} of chrysophytes were found at station 10 indicatin
the early summer, chrysophytes were numerous all over the lak
the main stations given earlier (Fig. 4.2) also demonstrated
group was ubiquitous at all stations in all seasons with some
a spring maximum. Highest biomasses of Chrysophyceae were fo
and near shore areas and reflect the poor water exchange with
lake.

The blue-green algae did well in both the main body of
the backwater areas (Figure 4.6). The region 1 values in Fig
not directly comparable in time with the other lake areas. C
of blue-green algae were found at station 10 at a depth of 0.
July 11. This would make this area more similar to region 4,
would be a strong contrast between it and region 7 which was
above. Except for one bay station, region 5 has a very low b

algal biomass as does most of the open-water of region 4. This distribution is probably related to the heating pattern of the lake, as these areas have lower temperatures than the rest of the lake in the spring. Previously, it was noted that the blue-green algae reached their maximum biomass contemporaneously at all the main stations, and this peak period coincided with the period of maximum surface water temperatures. The planktonic Cyanophyta are often characterized as warm water forms (Hutchinson, 1967).

Diatom distribution (Figure 4.7) contrasted markedly with the other groups. Region 7 and nearly all inshore stations had very low diatom biomasses. Highest biomasses were found in the main lake and river. The most comparable figure for region 1 was 166 $mg.m^{-3}$ rather than the higher biomasses found on July 30. Such a corrected figure would indicate that only the river and the northern portion of region 4 had high diatom biomasses in early July. All four groups showed high standing crops in the northern portion of region 4, and it can be speculated that the water in this area was a nutrient-rich remnant of the winter condition. All other portions of the lake have been stripped of the winter nutrient supply. The sub-dominant groups may also have been growing rapidly at that time although much of the biomass consisted of perennated Melosira. The higher biomasses found in the river demonstrate that phytoplankton growth in the river which is likely light limited will be out of phase with the lake and biomass importation could be significant in region 1. The pattern in region 1, although not comparable to the remainder in the lake, does demonstrate the pattern for July 30. Highest biomasses are found in the central portion of the basin downstream from the river. Higher light penetration in region 1 may account for this pattern. Melosira accounts entirely for the distribution of diatom biomass at this time (Figure 4.8) which is precisely what the main stations show.

In summary, the horizontal distribution of phytoplankton in July shows the following: 1) bays exchange water slowly with the open lake and consequently develop distinct algal populations; 2) warm water temperatures may favor blue-green algae; 3) high nutrients and/or turbulence effected by either wind stress, isothermal conditions or river flow favor Melosira; 4) disregarding the early Melosira peak in the lake, higher biomasses are found in the river early in the season; and 5) South Bay, region 6, has low biomasses of all groups when compared to other regions of the lake, i.e. conditions are unfavorable for all groups.

4.3. BIOASSAY EXPERIMENTS

Two experiments were conducted to assess the fertility of water from different regions of the lake at certain times of the year. The methodology for both experiments was similar. Water samples were collected in six-liter carboys, packed in ice, and flown to Winnipeg. All experiments were initiated within 24 hours of collection after passing the water through 87μ mesh to remove large zooplankton. Algal samples were incubated for three to six days, depending on the experiment, under constant light (4,400 lux; General Electric, cool-white fluorescent lamps) and temperature (10° or 15°C depending on lake temperatures).

Growth was monitored using the carbon-14 technique during incubation. Carbon-14 activity was estimated by liquid scintillation counting (New England Nuclear Aquasol scintillator solution; Packard Tricarb Liquid Scintillation spectrometer). Methods were similar to those described in the Provisional Algal Assay Procedure (Anon. 1969).

The algal transfer experiment consisted of introducing algae from one station into membrane-filtered (0.45 micrometer nominal pore size, Sartorius) water from another station. Ten ml of inoculum were introduced into 140 ml of medium and growth estimated after three days by the above method. This experiment was conducted to demonstrate the ability of waters from different lake regions and a local Shield lake, Isset, to yield crops of algae.

The nutrient enrichment study consisted of adding different nutrient combinations at different concentrations (Table 4.3), measuring the growth response after six days, and comparing the response with non-enriched controls. In theory this experiment should give an indication of what nutrients might be available in minimal quantities for growth. For the bioassay experiments, the dates of collection, stations sampled, type of experiment and pertinent information on the phytoplankton are given in Table 4.4.

The structure of these bioassay experiments necessarily produce an artificial situation and the most prominant deviations from the natural situation must be acknowledged and recalled when considering results. Two potentially limiting factors are removed, and one perhaps imposed. Many of the zooplankton are removed, and with them perhaps grazing pressure. A constant light environment is imposed, and the shallow flask depth rules out light limitation. Thirdly, nutrient limitation is necessarily imposed by the confinement of the water. In the natural situation there is a flow-through of nutrient mass whereas in a culture flask the mass is constant, and all batch cultures become senescent with time. Nutrient enrichment experiments can demonstrate which nutrient becomes limiting first in the flask and by inference which of those tested would be most likely to become scarce first in the natural situation. It does not necessarily follow that the limiting nutrient in the flask is a problem in the open natural system.

4.3.1. Growth of controls:

In conjunction with both experiments, controls were run. As the controls received the least manipulation their growth most closely approximates the natural situation, and offers a crude estimate of relative primary productivity under optimum light for the various stations. They can only serve for relative comparison, however, because of the artificiality of the experimental design (constant light, long incubation period, and zooplankton removal). Carbon-14 uptake was converted to total carbon by the following formula:

$$\text{C-12 assimilated} = \frac{(\text{Dissolved inorganic carbon})(\text{C-14 assimilated})}{1.06\ (\text{C-14 available})}$$

On August 21, 1972 controls for the nutrient enrichment experiment were incubated, and Figure 4.9 gives the results. Waters from stations 10, 20, and 30 incorporated significantly more carbon than waters from 40, 50, and 60. But the upper lake stations also had much greater initial biomasses. Carbon fixation is a function of algal standing crop as well as light, nutrients, and time. Therefore, a larger standing crop should exhibit a higher productivity if all other conditions are equal. In estimating the productive capacity of any given water the activity of the algae i.e. the amount of carbon fixed per unit of phytoplankton carbon is more significant. Algal volume can serve as an estimator of algal carbon (Vollenweider, 1968). To normalize the data from controls the carbon fixation was computed per unit of initial volume and then all values divided by the lowest computed activity ratio. Table 4.5 gives the results of the normalization and indicates that per unit of biomass station 60 was the most active followed by stations 50, 10, 20, 30, and 40. During incubation stations 60 and 50 exhibited the greatest relative growth while 10, 20, and 30 were very similar and station 40 was the least active. As incubation time and light conditions were identical,these normalized rankings which remove the bias of larger biomasses should reflect ambient nutrient concentrations of the different waters. The stations receiving only local Shield drainage appear to have adequate nutrients to sustain good growth in culture. The Southern Indian Lake stations receiving Churchill River water appear to be closer to nutrient limitation with station 40 especially likely to be nutrient limited. These activity rankings would suggest that the lower biomasses found at stations 50 and 60 are not the result of poor nutrient conditions *per se*.

On September 11, 1972 another set of controls were incubated as part of the algal transfer experiment. Waters from Isset Lake and stations 20, 50, and 60 in Southern Indian Lake were examined. No significant differences (at the 0.05 level) in carbon fixation (3 day incubation) were found despite large differences in initial biomasses (Fig. 4.10). Normalization of activity ratios as described above was performed (Table 4.6). Once again the stations receiving only local Shield water were more active than station 20 which receives Churchill River water. The results of the controls of these two experiments are consistent in suggesting that unused nutrients are more available at stations receiving local Shield drainage than at stations receiving Churchill River water. In reference to the model proposed earlier stations 50, 60 and Isset Lake don't appear to be strictly nutrient limited. Their low algal biomasses may reflect poor nutrient utilization because of low light (station 60) and/or grazing.

Grazing can be suggested for station 50 as this area of the lake has the highest density of zooplankton of any lake region (Patalas, 1974). On removal of these limiting parameters during incubation the productive capacity of these waters becomes visible.

4.3.2. Nutrient enrichment bioassay:

Subsequent to the initiation of the nutrient enrichment experiment it was discovered that the two highest levels of nutrient addition were unrealistically rich. As a result the highest levels often resulted in inhibition of growth. Therefore this discussion will be restricted to the results of the lowest level of enrichment. Interpretation of results is as follows. The addition of a nutrient singly removes any possible limitation by that nutrient. If a growth response is elicited, then adequate amounts of other nutrients are present. If no response occurs other nutrients are limiting growth; or the concentration of added nutrient is inhibitory. The addition of both nutrients together should give a response either similar in magnitude to the response of a limiting nutrient or greater than single additions. Figure 4.11 depicts the results of the experiment. All stations gave a response to phosphorus added alone. The P-enriched sample from station 50 was lost, but the strong response to N and P combined with the weak response to N suggests that it likewise would have shown a strong P response. All stations except 40 gave a response to nitrogen added alone, but the response was generally slight when compared to P alone. Again although the sample from station 10 to which N was added singly is missing, it can be seen that N and P together don't give a significantly greater response than P alone. This implies that nitrogen was not a problem at station 10. Addition of N and P together yielded a response comparable to or greater than either added singly with the exception of station 60. This suggests that the pronounced effect of P-addition on station 60 may have been an artifact. In summary, there was no evidence of nitrogen limitation at the stations tested. The clearest evidence for possible P-limitation was at station 40, but all stations with the possible exception of station 60 indicate that phosphorus is more likely to be a problem than nitrogen. These results were consisten with the activity of the controls where 40 gave the least growth and 60 gave the best growth. It must be cautioned that what holds true for the incubation flask need not occur in the lake, but it is clear that station 40 was closer to nutrient limitation than any of the other stations. The large increase in algal biomass at station 40 subsequent to August 21 was possible only because of biomass and nutrient loading carried in from region 3. Without this loading, algal biomass in region 4 would not be expected to increase significantly beyond the August value. The upper lake stations, 10, 20, and 30, have already been affected by recharge of nutrient-rich river-derived winter water while the lower lake station 40 has yet to be significantly affected.

4.3.3. Algal transfer bioassay:

The rationale of the algal transfer experiment is that the growth response of a uniform algal sample, inoculated into various media and incubated under identical conditions, will reflect the nutrient concentrati of the media. Inocula from four stations, 20, 50, 60 and Isset Lake, introduced into membrane-filtered water from each of the stations. Re flasks were done for each combination, and the results were statistica tested by analysis of variance with two-way classification. The resul are presented in Figure 4.12. The statistical testing revealed that different inocula had no significant effect at the .05 probability lev but the hypothesis that all media gave equal growth was rejected with greater than 99% certainty. Media from station 60 gave significantly greater growth than all the others (probability <.01). At the 0.05 le Isset media was significantly richer than station 50 water, but no significant difference was found between either Isset and station 20 o station 50 and station 20. The results from stations 20, 50, and 60 s the general conclusion of the nutrient enrichment experiment that stati 60 appears to be richer in nutrients than the other stations. The experiments do not demonstrate that station 50 is poorer in nutrients the other lake stations, and growth in controls suggests that station 5 water may have more unused nutrients than the stations receiving Church River water.

The results of the algal transfer experiment in combination with the growth of controls and nutrient enrichment bioassay indicate that nutrient limitation per se is an inadequate explanation for the lower standing crops of lake regions unaffected by the river. The availabili of light and grazing pressure must likely be considered as well to give plausible explanation. Stations on the Churchill River plume appear to be closer to nutrient limitation despite their much higher loading rate Sensitivity to nutrient enrichment and photosynthetic activity per unit biomass is a function of position along the axis of Churchill River on August 21, 1972. Upstream stations had more active populations th station 40. Subsequent increases in algal biomass would appear to re input of nutrients, and this observation gives insight into the impor of river flow to the productivity of river-influenced stations. The bioassay data provides useful information about the nutritional statu of algal populations from different lake regions which will be combi later in a descriptive model of productivity in Southern Indian Lake

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4.4. PRIMARY PRODUCTIVITY

The algal biomasses observed at the main stations of Souther
Indian Lake in 1972 suggested that the productivity of Churchill Ri
influenced stations was higher than stations receiving more local d
The horizontal distribution of algal standing crops as sampled in J
1972 indicated that the phytoplankton biomass was rather heterogene
distributed over the lake, and the distribution of other biological
populations (Patalas, 1974 and Hamilton, 1974) likewise indicated th
fairly discrete water masses existed in the lake. Biomass data can
difficult to interpret in terms of productivity as standing crops re
integration over time of the difference between processes adding org
and all processes leading to removal of organisms. A general statem
these processes for algae would be the following (Uhlmann, 1971):

1) $$\frac{dx}{dt} = \underset{\text{(import)}}{Dx_o} + \underset{\text{(growth)}}{\mu x} - \underset{\text{(export)}}{Dx} - \underset{\text{(grazing)}}{Gx} - \underset{\text{(sedimentation)}}{Bx}$$

and integration yields

2) $$x_t = x_o \exp(\mu - D - G - B)t$$

where x is algal biomass, t is time and μ, D, G, and B are the coeff
of reproduction, import or export, grazing, and sedimentation respect
Standing crop estimates tell us x_t, but offer no insight into the rel

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importance of the various additive and removal processes. In
except where advection is very significant, μ is the overwhel
process. The removal processes can vary markedly in relative
terms and are difficult to estimate. As μ reflects the amoun
algal biomass added to the system, it will be the most inform
coefficient in estimating a system's total production. Net p
productivity is the rate of new algal biomass production, and
is reasonably amenable to estimation. In August-September, 1
primary productivity measurements were made within short time
order to delineate primary productivity patterns in Southern
The goal of this particular task was to determine if the bioma
observed in 1972 were the result of changes in primary product
the lake or whether variations in removal processes, e.g. gra
sedimentation, could account for the observed patterns.

4.4.1. Methods:

The method of estimating *in situ* primary production fo
Indian Lake stations was essentially that of Fee (1973a) as s
modified (1973b). For the purposes of the model employed it
assumed that the phytoplankton are (1) uniformly distributed
vertically isothermal euphotic zone which is (3) optically ho
and (4) the physiological properties of the population (especi
productivity-light response curve) do not vary from sunrise t
The first three assumptions are easily met in Southern Indian
the suitability of the fourth is unknown. After the above as
are made, only three parameters require measurement

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in order to estimate *in situ* production: 1) the production-li
response curve of the phytoplankton; 2) the light extinction coef
and 3) incident light. The first parameter is estimated by incub
C-14 inoculated phytoplankton in a quantified light gradient. An
basically similar to that in Fee (1973a), but without the rotatio
was used for this purpose. Radiocarbon uptake in a dark bottle a
duplicate light bottles during a 4-hour incubation is monitored b
liquid scintillation counting by methods described in Schindler a
(1971) and Schindler *et al*. (1972). Dissolved inorganic carbon r
for estimating total carbon uptake by the equation given in Fee (
measured by gas chromatography (Stainton, 1973). Replication was
good. A typical light response curve is given in Figure 4.13.

Light penetration was measured with a selenium cell photom
Extinction is very rapid in these turbid waters; and, as extincti
depth is generally wavelength selective (Hutchinson 1957), ϵ_{min} (
1971) was probably measured. Light extinction for ϵ_{min} was nearl
below 0.5 m in every case as measured, but, extrapolation to the
from the first measured depth, 0.5 m, indicated that the extincti
coefficient in the first half meter was much larger even allowing
reflection (Hutchinson, 1957). High extinction in the first 0.5 m
depth may be attributed to scattering and absorption of the most s
wavelengths. No attempt was made to quantify this further. The v
ϵ_{min} applies over most of the euphotic zone, and no correction for
purposes of this study was deemed necessary. Incident surface rad
was measured with a Kipp-Zonen pyranometer placed at South Indi

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Post. Data from this instrument were used to estimate day le
maximum intensity of total surface radiation. To estimate da
productivity by the model a surface irradiation curve was con
using the measured I_{max} (clear sky at mid-day) and day length
relationship. This gives all stations the same light environ
day) and renders all stations comparable as well as giving ex
production on a clear day. Again for the purposes of this re
to demonstrate patterns of production and the relationship to
production of stations under equal lighting conditions is of
interest than real *in situ* production on any particular day a
conditions and *in situ* production can be highly variable (Fee
The assumption that average light conditions over the entire
equivalent should not be greatly violated in the long term, a
differences in productivity should be caused by factors unrel
light.

Water sampled for incubation were taken at 0.5 m depth
van Dorn bottle and transported in two-liter opaque polypropy
Samples for chlorophyll determination and phytoplankton chara
were taken from the same van Dorn sample. A subsequent two-l
was taken with the van Dorn bottle and also stored in an opaq
This second bottle was used for determination of total suspen
suspended carbon, nitrogen, and phosphorus, total dissolved p
total dissolved nitrogen, dissolved inorganic carbon, dissolv
carbon, nitrate, silicate, and phosphate. The methods used w
described by Cleugh (1974) except that larger volumes were fi

suspended materials. After collection the two-liter opaque sample bottles were placed in a cooler. Measurements of temperature and light extinction were made at each station.

All sampling was done from a float plane. Six stations were taken each day generally between 10:00 a.m. and noon. Samples were then flown to Thompson where the incubator and other equipment was set up. The maximum time lapse between collection and incubation was four hours. Temperature changes during transport were negligible. Samples for suspended materials were filtered on return to Thompson while water for analysis of dissolved nutrients (except phosphate) was sent to Winnipeg for analysis. Phosphate-phosphorus (soluble reactive phosphate) was estimated spectrophotometrically in Thompson within six hours of collection. The approximate locations of the stations are given in Figures 4.14 and 4.15.

4.4.2. Results:

A total of 29 productivity stations were made on Southern Indian Lake in September, 1973. Between September 1 and September 3, 18 stations were accomplished while 12 stations were made on September 28 and 29. The timing was chosen on the basis of the 1972 sampling which showed a maximum differentiation of standing crop at this time. In 1972 during this time interval, stations in region 4 were undergoing substantial increases in biomass (Figure 4.1) while the upper lake regions (1 and 2) showed declining biomasses. If patterns of productivity exist in the lake, they should be evident during this time.

The early September sampling (Figure 4.14) appears to show that at this time of year primary production is highly variable and dependent to a large extent on the location in the lake. In Table 4.7 the relevant productivity data for the first sampling period are recorded while Table 4.8 gives the results of nutrient analyses conducted at the same time. The highest production values (880-1,300 mg $C.m^{-2}.day^{-1}$)were estimated for region 4 (stations 40, 41, 47, and 51) while the lowest (117-312 mg $C.m^{-2}.day^{-1}$) were found in region 6 (stations 60 and 61). Region 1 (stations 10, 11, 13, and 19) exhibits a range from 600 to 900 mg $C.m^{-2}.day^{-1}$ which is comparable to region 2 (stations 20 and 22) with a range of 740 to 880 mg $C.m^{-2}.day^{-1}$. In regions 1 and 2 there is a tendency for stations off the apparent main axis of flow (stations 13, 19, and 22) to have somewhat lower productivity than those stations on the main axis (10, 11, and 20). This apparent pattern breaks down in region 3 where the off-stream station 36 is much more productive 1,120 mg $C.m^{-2}.day^{-1}$ while the on-stream station 30 is more comparable to stations in regions 1 and 2 at 760 mg $C.m^{-2}.day^{-1}$. The characterization of on-stream and off-stream is based on the water mass identification of Patalas (1974) which was observed in 1972. The boundaries of these water masses may be highly mobile, however, and an "eyeball" field classification misleading.

Those lake regions which receive little or no Churchill River water exhibited slightly lower to greatly reduced productivity. Region 5, best represented by station 50 which had a production of 680 mg $C.m^{-2}.day^{-1}$, was lower than any station in regions 1-4 with the exception of station 19 which may receive much of its water from Shield drainage in region 7. Station 52 in a bay flushed by the Muskwesi River had a much lower daily integral productivity of 284 mg $C.m^{-2}.day^{-1}$. Its lower production relative to station 50 resulted from the lower light penetration. Its optimum volumetric rate, 12.5 mg $C.m^{-3}.day^{-1}$, was substantially higher than that of station 50 which indicates that a higher biomass and/or more nutrients were present at 52. Station 79 in region 7 had a volumetric optimum rate comparable to most of the stations in the main lake, again indicating a reasonable supply of nutrients, but the calculated daily integral rate is slightly lower because of greater light extinction. This river (79) has the highest calculated flow of any river entering the lake except for the Churchill River itself and the Barrington River (Cleugh, 1974). The relatively high flow brings the mixed blessing of high nutrient supply and turbidity. Region 6, stations 60 and 61, had the lowest optimum volumetric rate of any of the stations measured, and also the lowest daily integral production.

The second productivity survey made at the end of September (Figure 4.15) found the lake significantly less productive. Two stations not measured on the first trip were added. Station 02 was chosen to represent the Barrington River while station 12 was sampled to represent region 1. Lack of time eliminated eight stations of the first trip. Only three stations registered an increase. Station 19 increased from 600 to 1,000 mg $C.m^{-2}.day^{-1}$ while both stations in region 6 increased. Despite the increased production in region 6 it was still by far the least productive area of the lake. With the exception of station 19 the productivity patterns noted on the second trip were the same as the first trip. Although the daily integral clearly decreased for most every station, the optimum volumetric rate was more stable. The difference in integral productivity can be attributed to a decline in light penetration between the two dates. In general, although the integral rates are lower, the general pattern of productivity is similar to the early September estimates. Region 6 is still the lowest and region 4 is the most productive while regions 1, 2, 3 and 5 are intermediate and comparable. Station 02, representative of the Barrington River, is much less productive than station 06, the Churchill River. Although light extinction is nearly identical at both stations, station 02 has lower values for chlorophyll, optimum volumetric rate, and integral productivity. The assimilation ratio which indicates the amount of carbon fixed at optimum light per mg of chlorophyll a is also much lower at station 02 suggesting that nutrients are less available at 02 at this time. These two rivers are the major source of inflow to Southern Indian Lake. Clearly in late September, at least, the waters of the Barrington are less conducive to algal productivity than the Churchill River. Without the Churchill, Southern Indian Lake would be much less productive than it is.

Assimilation ratio is often used as an index to the efficiency of light energy utilization of the phytoplankton. As light is optimized, the availability of nutrients is most likely responsible for differences in this ratio between stations. In both early and late September the lowest values for this ratio are found in non-Churchill waters while the highest values occur in region 4. It is instructive to compare the assimilation ratio for station 36 with the stations in region 4 (40, 41, 47, and 51) for the early September trip. Although the daily integral for all these stations was nearly identical as were the optimum volumetric rates, the assimilation ratios of the region 4 stations are much higher than that of station 36. This probably indicates that nutrients were more available in region 4 at the time.

The nutrient concentrations measured in conjunction with the productivity estimates are tabulated in Table 4.8. Phosphate-phosphorus and nitrate-nitrogen were measured only on the second trip. Nitrate was low, but generally detectable at all stations while phosphate (soluble reactive phosphate) was detectable at only four stations. Although two of the stations (40 and 47) with detectable phosphate were quite productive the other two (22 and 50) were not extraordinary. The relationship of molybdate-reactive phosphate-phosphorus (SRP) to phosphate available to phytoplankton is not well understood (D.W. Schindler, personal communication) and the ambiguity of the above results is perhaps not surprising. Similar problems are attendant to interpreting total dissolved nitrogen and total dissolved phosphorus. Values for TDN and TDP in Southern Indian Lake are much higher than the mean values at the Experimental Lakes Area (TDN = 177 $\mu g.l^{-1}$; TDP = 7 $\mu g.l^{-1}$). Based on these values alone Southern Indian Lake would be considered a more nutrient-rich environment than ELA and higher productivity would be expected. However, within Southern Indian Lake there is no clearly discernible pattern of TDN and TDP distribution comparable to that observed for integral primary productivity. For example the TDP concentrations of stations 06 and 40 at opposite ends of the lake were comparable on both trips. Similarly the concentrations of TDP found in Churchill-derived and non-Churchill waters were generally comparable.

Concentrations of dissolved inorganic and organic carbon tend to be higher at all stations on the second trip although no explanation can be offered from the information at hand. Suspended carbon tends to be lower at all stations on the later trip, with the exception of stations 40, 47, and 50; but the decreases in suspended carbon do not nearly balance the apparent increases in DIC and DOC. Atmospheric exchange of CO_2 is presumably involved (Schindler _et al._, 1973) as well as regeneration of organic compounds from sediments. Suspended nitrogen and phosphorus do not show any consistent changes between trips. Total suspended solids were much higher on the average during the first trip with a gradient in values from region 1 (average TSS = 2.8 $mg.l^{-1}$) to region 4 (1.3 $mg.l^{-1}$). On the second trip low values were found all over the lake, and it may be that this parameter is temporally variable with resuspension during turbulent conditions being a significant component of measured values.

Dissolved silicon may be the best indicator of algal activity among all the parameters measured. In 1972 in late September diatoms were the dominant phytoplankters in all regions of the lake except for 6 and 7. Diatoms have silicified cell walls, and concomitantly their growth creates a Si demand. If demand exceeds supply (from inflows and regeneration), Si concentrations will fall. Only in region 4 were declining Si concentrations observed, and this correlates with the measured primary productivity of the region which was the highest in the lake over this time interval. In regions 1, 2, and 3, Si concentrations were either unchanged or higher during the second trip suggesting reduced diatom activity and resupply of Si from dissolving frustules.

4.4.3. Discussion:

In Southern Indian Lake in September, 1973, Churchill-derived waters were more productive than non-Churchill waters and the lower lake, region 4 was the most productive area in the lake. This pattern is that which would be expected from the biomass distribution observed in September, 1972. This correlation supports the view that algal biomass reflects algal growth rates, μ of equation 1, and means that losses due to grazing, sinking, and export are approximately similar throughout the lake. Along the axis of flow of the Churchill River the highest integral productivity values are found in region 4. These higher values reflect, primarily, lower light extinction coefficients for waters in this region compared to other regions. The average optimum volumetric rate for region 1 is only 10% lower than that for region 4, but the light extinction coefficient for region 1 is nearly 50% greater than that of region 4 in September. The average daily integral in September is approximately 50% greater in region 4 than in region 1. Clearly the increased depth of the euphotic zone has a positive effect on integral productivity and consequently biomass in the mainstem regions of the lake.

The richer nutrient status of Churchill River water as compared to non-Churchill River water is made clear when region 4 is compared with region 5. The light extinction coefficient for region 5 is lower than in region 4, but integral productivity, optimum volumetric rate and assimilation ratio are all lower. Lower nutrient availability can be invoked (see section on nutrient loading), but it is noteworthy that integral production in region 5 approximates that in regions 1 and 2 at this time of year (and annually if biomass values are compared, Table 4.1). This demonstrates that increased light penetration can offset lower nutrient supply to a certain extent. MacIsaac and Dugdale (1972) demonstrated that the availability of light can influence the efficiency of nutrient utilization. Region 6, also with only local drainage, is much less productive than region 5 although it will later be shown that its nutrient loading rate is comparable to region 5. Here again the significance of light penetration is apparent. The light extinction coefficients in region 6 are comparable to those in region 1, but the estimated integral for region 6 is only one-half or less than those of region 1. The heterogeneity of nutrient and light conditions in different parts of the lake renders generalization about a single limiting factor difficult as will be discussed later.

Comparable productivity values for other lakes of northern Manitoba and Saskatchewan are quite scarce. The nearest group of well studied lakes for which productivity values exist are in the Experimental Lakes Area of northwestern Ontario over 600 miles to the south. Schindler and Holmgren (1971) report typical midsummer integral values for ELA lakes ranging from 210 to 1,500 mg $C.m^{-2}.day^{-1}$ which is comparable to the range observed in Southern Indian Lake. Estimated integral productivity for other Shield waters, e.g. Great Bear Lake, Great Slave Lake, and eastern Lake Winnipeg were substantially lower than ELA lakes or Southern Indian Lake. It would appear from the fragmentary data available for other large Shield lakes that Southern Indian Lake is substantially more productive than Shield lakes of comparable size and latitude. The high nutrient loading supplied by the Churchill River is probably responsible.

4.5. INTERRELATIONSHIPS OF LIGHT, ALGAL BIOMASS, CHLOROPHYLL, AND SUSPENDED MATERIALS

Previous presentations of biomass, bioassay and in situ productivity data suggested possible interrelationships of light, suspended materials, nutrients, and production. Numerous simple correlation coefficients have been calculated to determine: a) what factors may control light penetration; b) the relationship between light penetration and algal standing crops; and c) the relationship between chlorophyll and biomass. Groups of data subjected to analyses were two synoptic surveys for which Secchi disc depths, total suspended solids, and chlorophyll concentrations were available. These data were chosen for correlation analysis as they constituted the largest data sets available which were collected in a reasonably short length of time. These parameters were measured as part of the benthos (July, 1972) and zooplankton (August, 1972) surveys. Phytoplankton samples were taken in the July survey and algal biomass data are available for it. In addition, linear correlation coefficients were calculated for the seasonal main station data on algal biomass, chlorophyll, and Secchi disc depths.

In July, a highly significant negative correlation was found between the Secchi disc depth (s.d.) and total suspended solids (s.d. (m) = 2.0 m - 0.04 T.S.S. ($mg.l^{-1}$) $r = 0.40$, $n = 57$, $p < 0.005$) (Figure 4.16). Total suspended solids is the sum of all living and non-living solid materials in the water. To see if the above correlation could be attributed to living material, linear regression lines were derived for Secchi disc depths on chlorophyll and algal biomass. The chlorophyll relationship although negative was not significant, ($p < .05$) and, while the algal biomass had a significant relationship (Figure 4.17), the slope was positive, not negative (s.d. (m) = 1.3 + 0.00064 biomass (mg.m^{-3}); r = 0.44, n = 53, $p < 0.001$). The living component of T.S.S. did not appear to be a significant contributor to light attenuation in July.

For the August survey, similar data analyses were performed. Onc again, a highly significant negative correlation was found between Secch disc depth and total suspended solids (s.d. (m) = 2.2 - 0.06 T.S.S. (mg. r = 0.50, n = 58, $p < 0.001$) (Figure 4.18). Secchi disc on chlorophyll, however, gave a significant positive correlation (s.d. (m) = 0.817 + 0.1 chl (mg.m^{-3}); r = 0.34, n = 57, $p < 0.02$) (Figure 4.19). As no phytoplan samples were collected in this survey, algal biomass data are not availa These two surveys indicate that Secchi disc depth decreases as the detri suspended load increases. Because the Secchi disc reading is responsive to total suspended solids, it may reflect sedimentation patterns in the lake. The Churchill River is by far the most important source of suspen sediments, and total suspended sediments should decrease from this source along the axis of the lake. Light penetration would improve along the a as Table 4.2 indicates. Algal biomass correlates positively with light penetration because: a) for any depth more light energy is available fo photosynthesis and b) algae and their pigments do not contribute greatly to light extinction in the concentrations they achieve in Southern India Lake.

Other correlations tested on the data were chlorophyll and compu algal biomass. For the July synoptic survey a significant positive correlation was found (chl mg.m^{-3}) = 2.7 + .0016 biomass (mg.m^{-3}); $r = 0.45$, $n = 53$, $p<0.001$) (Figure 4.20). Such a correlation supports the general supposition of algal ecology that chlorophyll can serve as an estimate of standing crop, but the y-intercept is uncomfortably high. Possible explanations would include a high background level of chlorophy degradation products (e.g. phaeophytin) and some samples with anomalousl low chlorophyll for a high biomass (and/or vice versa) which would lower the slope of the curve and raise the intercept. In a shallow, non-stratified lake such as Southern Indian Lake, chlorophyll degradation products could possibly remain in suspension or be resuspended throughou the growing season. For this reason, a rather high background level mig exist. Alternatively, as chlorophyll content is a function of the nutri state of the algae and the previous light history, under certain conditi high biomasses with low chlorophyll are possible. In this regard it mus be noted that the two highest points in Figure 4.20 are from the norther portion of region 4 where Melosira spp. constituted nearly all the bioma and the low ratio may be indicative of their activity. Further complica factors are the variable chlorophyll content recorded for different alga groups in culture and extractability of different groups (Strickland, 19

All these contributing sources of variation might be compounded over a whole season, but the data from the main stations (09, 10, 20, 30 40, 50, 60, 49b) indicate that seasonality plays a minor role. Again a significant positive correlation is found (chl = 2.18 + 0.0013 biomass (mg.m^{-3}); $r = 0.45$, $n = 47$, $p <0.005$) (Figure 4.21), and the slope and intercept are nearly the same as the July data. Samples from the s Melosira peaks are indicated on Figure 4.20, and again the chloropl content of these peaks is consistently low. Although the expected correlation is present, the high intercept and low slope of the re lines indicate that in Southern Indian Lake, chlorophyll a, by its not serve as a good predictor of biomass.

The relationship between chlorophyll and nutrient status, might be more meaningful. If mean chlorophyll concentrations at 0 are computed, the upper lake stations 09, 10, 20, and 30 are found more chlorophyll than the lower lake, region 4, region 5 and regio (Table 4.9); and nutrient availability might exhibit the same patt Chlorophyll:biomass weight ratios indicate that algae from the upp have a higher extractable chlorophyll content than algae of region an equivalent unit of biomass, while region 6 is the highest. Alg composition may explain this pattern in part, but not entirely, e. October 3 station 30 had a ratio of 0.0036, while station 40 had a of 0.00099 and the taxonomic composition was nearly identical, 81- Melosira (Figure 4.1). Chlorophyll content is a function of nutr status (Healey, 1973), and nutrient limitation was likely at stati at this time as the bioassay experiments demonstrated. Ratios fro literature and culture work (Healey, 1973 and personal communicati indicate that a ratio of 0.002 to 0.003 would be a cutoff for nutr limitation. By this criterion and Table 4.9 which gives mean valu stations 40 and 50 would be considered to be under or near nutrien limitation much of the time. It is also possible that some of the season biomass maximum in region 4 represents resuspension of inactive cells, as the lake cooled under isothermal conditions. In general, th chlorophyll:biomass ratios reflect the expected pattern of nutrient availability in the lake, i.e. higher near inflow, lower near outflow. It must be noted that all the ratios in Table 4.9 are higher than the slope of the regression lines given above. The extremely low ratios o the highest biomasses recorded and the high ratios for low biomasses i region 6 have obviously reduced the slope markedly.

2

4.6. SUMMARY OF ANNUAL CYCLE OF PHYTOPLANKTON AND PRODUCTIO

Southern Indian Lake in 1972 exhibited a simple bimodal
phytoplankton production. Although a single year's data can be
the time constraints of the study require that it be taken as pa
Winter production under ice and snow is light-limited and low st
crops are observed. During the winter, the main lake portions d
on the Churchill plume are completely flushed and nutrient conce
in river and lake are identical. Ice-out in the spring allows l
populations of Melosira spp. (perhaps the highest standing crops
year) taking advantage of the nutrient-rich conditions. Rapid n
drawdown occurs and the first seasonal peak of production is pro
terminated by a combination of nutrient depletion and reduced tu
Subsequent biomass production is dependent on nutrient recharge
nutrient-rich water from the Churchill River. Upstream lake are
the second peak in production before downstream areas with the t
a function of flow through the lake. Region 1 attains its secon
six to eight weeks before region 4.

The magnitude of the biomass and productivity maxima is
by light penetration. Sedimentation of suspended silts and clay
turbid river enters and moves through the lake reduces total sus
solids and increases light penetration. Secchi disc depths incr
factor of two from region 1 through region 4. Mixing depth (= m
in the unstratified lake) increases by approximately 50% from re
through region 4. The result is that phytoplankton cells are ex

suitable light conditions longer in region 4, and consequently more energy is available for photosynthesis (Murphy (1962) develops the relationship between mixing depth and depth of euphotic zone in greater detail). Although nutrients are likely to be less available downstream, the deeper euphotic zone allows more efficient use of nutrients. Therefore, regions 3 and 4 are the most productive areas of the lake.

Regions 5 and 6 are much less productive than the Churchill influenced regions. The primary cause is much lower nutrient loading. In region 5, production is not reduced in proportion to loading primarily because light penetration is the highest in the lake. In region 6 the low nutrient loading is aggravated by poor light conditions. Again the ratio euphotic zone depth to mixing depth indicates that less energy is available for production in region 6. Although nutrient loading estimates for the two regions are similar, nutrients in region 6 are less efficiently utilized; and therefore, more available when light is optimized as in the bioassay experiments.

Primary production and biomass estimates indicate that most of Southern Indian Lake would be considered oligotrophic. Region 4 might be considered mesotrophic to eutrophic. Although annual estimates of primary productivity are not possible yet, the lake appears to compare favorably with lakes farther to the south, e.g. Lake Winnipeg and the Experimental Lakes Area. Primary productivity is not as high as might be expected from nutrient loading considerations (section 4.7) probably because high light extinction retards nutrient utilization. The high discharge of the Churchill River is crucial to the productivity of the lake as it guarantees a high nutrient supply. Areas off the main flow have much lower production (10% to 80% of regions 1-4). Without the Churchill River the lake would be much less productive than it is.

4.7. NUTRIENT LOADING

4.7.1. Present and post-diversion nutrient loading:

For many lakes an empirical relationship between the rate of essential nutrient input (loading) and the trophic status of a lake has been demonstrated (Vollenweider, 1968; I.J.C., 1969). In Cleugh (1974) the phosphorus loading rate for Southern Indian Lake and its various basins were presented. These calculated rates indicated that those areas of Southern Indian Lake receiving Churchill River water fell well within the eutrophic portion of Vollenweider's formulation. However as discussed in section 4.2.2.1 the observed algal standing crops are not consistent with such a ranking as even the highest biomass observed would indicate only mesotrophic conditions while the average of the maxima from various stations would be considered oligotrophic to ultra-oligotrophic. This discrepancy requires consideration and explanation especially if predictions of the consequences of reduced loading are desired.

Vollenweider's model makes at least four assumptions which were generally well founded for the lakes he considered. These are: 1) phosphorus is biomass limiting; 2) most of the various forms of phosphorus contributed to the lake become available to the algae while the water is resident in the lake, i.e. total phosphorus is used for the calculation; 3) dilution of phosphorus loading is proportional only to volume; and 4) for the area and volume considered mixing is adequate for the obliteration of highly localized conditions especially at sources, i.e. phosphorus loading is rather equitably distributed over the lacustrine space under consideration.

The first assumption appears reasonable for Southern Indian Lake. The bioassay tests revealed that waters from most lake regions (with the possible exception of region 6) gave their strongest response to phosphorus enrichment. This suggests that phosphorus is most likely to become limiting although we have not demonstrated that limitation does occur. In fact there is evidence that low light and grazing retard biomass accumulation in many parts of the lake. Only in region 4 does the evidence for nutrient limitation appear especially convincing. The second assumption is more problematical. Most of the lakes considered within Vollenweider's original framework already received significant cultural enrichment which means that orthophosphate, the form utilized by plants, probably constituted a large fraction of the total phosphorus. Other phosphorus fractions are not so available to plants and require time for degradation processes to make the contained phosphorus available. Vollenweider gives apatite as an example, but in Southern Indian Lake humic compounds may be a sequestering agent of equal import. Breakdown of such compounds is slow and appreciable time may be required to release phosphorus from them. The third assumption of dilution being proportional only to volume may also be inapplicable to Southern Indian Lake as the turnover time especially for Churchill river water is quite low, on the order of two to three months. Flushing, therefore, may be significant in terms of nutrient loading and biomass loading. Flushing in the winter is especially significant as the prolonged ice cover reduces winter productivity and the nutrients pass through unavailable to the algae. This accounts in part for the low annual nutrient retention (10% for P); but, even if only summer loading is considered, retention is low, about 20% for P. The last assumption of Vollenweider's model makes application of his loading formula difficult for Southern Indian Lake. Over 90% of the phosphorus loading to the Southern Indian Lake basin occurs via the Churchill River, but this loading is not distributed over the entire lake. Rather, a discrete plume is maintained and the lacustrine volume affected may be less than one-half the total contiguous volume (Patalas, 1974). Therefore it is unreasonable to calculate loading per unit of total surface area, as the loading is not equitably distributed.

The Churchill River plume is a high loading, high flow situation while regions 5, 6, and areas of regions 1, 2, 3, and 4 experience low loading and low flow. Low loading means less total phosphorus available but low flow allows more time for utilization with the converse being true for high loading and high flow. This implies that a loading decrease in a high flow system can be offset to a degree by reduced flow. Vollenweider is currently extending his formulation to lakes with a high turnover (D.W. Schindler, pers. comm.); but, until the quantification is available, it is perhaps safer to attempt comparisons within Southern Indian Lake. Regions 5 and 6 are rather discrete bodies of water for which current loading can be calculated. Estimated loading for region 5 above Sand Point is 0.023 g P $m^2.yr^{-1}$ while loading for South Bay (region 6) is 0.018 g P $m^2.yr^{-1}$. The mean depth for region 5 is 5.3 m while that of South Bay is 3.9 m, and the water residence times are similar being on the order of 3 years (South Bay) to 4 years (region 5). For all practical purposes the loading rates and turnover times can be considered equivalent.

Vollenweider's formulation would predict ultra-oligotrophy and the alga biomass data and primary productivity are consistent with this. South Bay's average phytoplankton standing crop and productivity in the summe is roughly one third that of region 5 (Table 4.1) and the difference is probably attributable to reduced light penetration in South Bay (Table Long term loading rates for regions 3 and 4 after diversion have been estimated (Cleugh, 1974) as 0.2 g P.m^{-2} and the average residence time Churchill River water will exceed two years. Mean depth for these regi after impoundment will be approximately 12 m. Under post-diversion conditions, i.e. low flushing, Vollenweider's model would be more appli and it would predict a mesotrophic state. Loading to regions 3 and 4 a diversion will exceed the present loading to regions 5 and 6 by at leas a factor of four. From these considerations alone it is unlikely that the long-term productivity of regions 3 and 4 would fall as low as the present status of region 5. Standing crops and productivity in region 5 currently average roughly one-half to two-thirds those of regions 3 a 4. It can be concluded that the loss of nutrient loading because of diversion will be offset to a certain extent by reduced flushing.

4.7.2. Nutrient and sediment loading resulting from impoundment:

The previous discussion (section 4.7.1) treats the effects of diversion and impact as a purely mechanical alteration of the present system. This may not be unreasonable for the long term, but impoundmen will create new sources of loading which will endure for some time. Th current shoreline is the result of several thousand years of developmen and is in long-term equilibrium with the hydrological regime. Water contact along most of the lake's shoreline is with either bedrock or sand and gravel beaches and very little net erosion occurs from the present shoreline (excepting South Bay).

Erosion of the new shoreline will leach nutrients and remove particulate matter. The former process will increase nutrient loading while the latter will result in increased turbidity and light extinction in inshore areas. The effects of shoreline stabilization will be most immediately and forcefully felt in near-shore regions. The best example of these processes in the Southern Indian Lake basin is Swan Bay which is the shallow, elongated southeast arm of South Bay (region 6). The average depth of Swan Bay is approximately 1.5 m and the average Secchi disc value is 0.1 m. Secchi disc values of less than 1 m are representative of all the shallow bays on the south and east side of South Bay. Wind generated turbulence suspends the glacio-lacustrine clay eroded from shorelines and bottoms of these areas and wind driven circulation introduces quite visible sediment plumes into South Bay proper. The transparency of the water improves noticeably through the bay (station 60 average Secchi disc is 1.4 m) and into the South Bay channel to Southern Indian Lake proper as sedimentation occurs. The same general pattern should accompany stabilization of the new shoreline (Hecky, 1974). In the immediate vicinity of erosive contacts extreme light attenuation will occur as sediment plumes move into offshore areas of greater depths where sedimentation will increase light penetration and allow algal populations to utilize the nutrient loading. The suspended materials will be removed as deeper water decreases the turbulent energy required for resuspensi The nutrients released into solution will be more widespread and dependent in part on biological processes for their removal. Outside the Churchill River plume nutrient loading is presently low, and thus added loading from shoreline erosion should increase the productivity inshore areas in the short term unless light becomes critical. The hi complex shoreline and diverse water sources favor the creation of nume water masses. Chemical, faunistic, and floristic data demonstrate tha many of these water masses mix slowly with each other. This aspect an the uneven distribution of erodible material in the basin will tend to localize the affects of shoreline stabilization and render general prediction difficult. Even if the distribution of glaciolacustrine cl and the quantities of suspended materials and nutrients likely to be eroded were accurately known, there is no general relationship availab to predict with any certainty the likely effect on light transparency, nutrient loading, and productivity. A great deal of research to estab quantitative empirical relations for these processes is long overdue i view of man's continuing desire to manipulate his aquatic habitats.

4.8. PROBABLE EFFECTS OF THE SOUTHERN INDIAN LAKE IMPOUNDMENT AND SOUTH BAY DIVERSION ON THE PHYTOPLANKTON ECOLOGY OF SOUTHERN INDIAN LAKE

The hydroelectric development of Southern Indian Lake will result in a larger and deeper lake with a new regime of water movement. Impact of this development is best evaluated in terms of short-term and long-term (essentially permanent for our life span) effects. Short-term effects will be those related to impoundment and shoreline stabilization while long-term effects will derive from the new morphometry and hydrographic regime. The effect of these alterations on the chemical and physical environment will be of significance to the phytoplankton production of the lake. Nutrients and light are essential environmental parameters which are amenable to prediction as the interrelationships with production, though not simple, are well studied. Higher order parameters, such as turbulence, grazing, parasitism, antibiosis, etc., are more complex and poorly understood; predictions about possible effects can't be made with any certainty.

Southern Indian Lake is highly complex as the discussions of morphometry, chemistry, flora, and fauna demonstrate. The lake was provisionally divided into several major morphometric regions to facilitate sampling design and discussion. Subsequent work has indicated that even these subdivisions are not completely adequate to delimit water masses within the lake, but further partitioning is precluded within the time limits of the present study. Therefore probable impacts will be evaluated within the simpler regional framework.

1. Opachuanau Lake and regions 1 and 2 of Southern Indian Lake.

The upper lake regions, above and in the immediate vicinity of the inlet to South Bay will undergo the least modification of their bas hydrological regime. Mean depth, volume, and area will increase in long term while the input of nutrients and water from the Churchill and other streams remain unchanged. Loading per unit volume will d as will turnover, but these effects will be largely offsetting. Th range prognosis is for productivity to equal or slightly exceed pre levels. The pattern of a discrete river plume exchanging water slo with inshore bays and region 7 will be unchanged. This partitionin water masses will tend to restrict nutrient and sediment loading associated with shoreline stabilization to nearshore waters. Shall in the immediate vicinity of erosive contacts will be light-limited high turbidity while deeper offshore areas will be unchanged. Heck indicates that these regions have the least potential for erosive r of suspended materials of any part of the lake.

2. Regions 3 and 4.

These regions will have a drastically altered regime. Annu loading will be reduced by 90% and will become highly seasonal. Al greatly reduced, long-term loading will still be several times grea than that in region 5 today. The greatest loss in loading will occ winter when essentially no Churchill River water will enter this re Under the present regime this winter loading is partially unavailab algae because of the high flushing rate, but it does insure high nu concentrations for ice-out in the spring. Loss of this winter load will be evident in the reduced magnitude and duration of the spring The quantitative role of this spring bloom in the annual production lake can't be estimated from present data. Summer loading will be redu to 20% of its present level, but the lower loading should be offset in part by a longer residence time for the water and clarification because of sedimentation which will allow greater use of the loading as light penetration improves. The longer residence time will also allow better mixing, and region 4 especially will be more homogeneous. Summer stand crops should exceed those in region 5 as discussed in section 4.7.1. S term effects will be similar to those forecast for regions 1 and 2. Ho the river plume will not be as well-delimited in these regions and bett mixing of inshore and offshore waters will occur. The additional loadi which shoreline erosion will yield will be more evenly distributed as w the resulting productivity. This will tend to offset partially the los loading from the Churchill River. But this source will decline over ti and so will the productivity of the whole region. Immediately post-div inshore, shallow areas will likely be light-limited by turbidity, and nutrients will be used in offshore areas as discussed for regions 1 and The long range forecast for these regions is a declining productivity stabilizing at one-half to two-thirds the present level.

The above discussion of impact is based on a long-term loading amounting to 15% of the present level. However, such a characterizatio may be deceptive. Manitoba Hydro's interim license calls for minimum f of 500 cfs in summer and 1,500 cfs in winter. If the lake were subject to this outflow for an extended period of time, productivity would be reduced even further as loading would only amount to 3% of its present level for regions 3 and 4. Unfortunately the probability of operation

with minimum flows at Missi Falls appears to be substantial.
Resources Branch (1973) has modeled the modified historic disc
Missi Falls. This modified record indicates that in the dry y
1930's and early 1940's minimum allowable discharges (500 cfs
1500 cfs winter) would have been enforced for a great length o
Such an extremely low loading rate would be completely unaccep
it would create catastrophic declines in production and the co
fishery would be severely affected. It is strongly recommende
minimum allowable discharges be increased to guarantee a minin
discharge of 5,000 cfs at Missi Falls. On present knowledge t
lowest acceptable level consistent with maintaining Southern I
as a productive fisheries resource. After diversion has been
several years, experience with the system may indicate that le
might be acceptable, but with present information a gradual st
reduction in minimum discharges would be prudent.

3. Regions 5 and 7.

These regions will only be affected by water quality c
resulting from inundation. Both areas will be subjected to hi
loading rates while the new shore lines stabilize. High turbi
decrease productivity in the shallow northern region of region
the shallow bay where the Muskwesi River enters. The deeper p
region 5 will exhibit higher productivity because of the highe
loading. Region 7 is bounded by relatively steep cliffs along
its perimeter, and turbidity and nutrient loading may not cha
After shoreline stabilization productivity will be somewhat l

today because of the increased volume and mean depth.

4. Region 6.

South Bay will be markedly affected by the increased flow thr it. If the whole volume of the post-diversion bay is considered a residence time of only 10 days is calculated. More than likely the f through will be largely restricted to the western side of the bay and complete flushing will occur every few days. With a turnover time th low, the bay will simply reflect events in regions 1 and 2 and nearly its standing crop will be imported. However, inundation effects in a off the mainflow will aggravate the present South Bay situation. In S Bay, at the southeast corner of South Bay, clay cliffs are being acti eroded, and this is responsible along with the shallow depth of South Bay for the present high turbidity and low productivity. The shallow mean depth allows continual resuspension by wind-induced turbulence o sediment produced in Swan Bay. Therefore, the eastern side of the ba may have lower light penetration than presently and algal productivit may not change markedly.

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Table 4.1. Maximum annual biomass attained at each lake station and average biomass for the four month growing season monitored in 1972. Biomass in $mg.m^{-3}$.

Station	10	20	30	40	49b	50	60
Maximum	1590	1980	2280	3000	4400	1630	500
Average	1130	1260	1400	1650	1950	970	310

Table 4.2. Secchi disc depths (m) by station and date.

	10	20	30	40	50	60
June 21	1.3	1.3	1.4	2.2	2.0	1.3
July 11	1.3	1.3	1.5	2.0	1.9	1.3
July 31	1.3	1.5	1.7	1.6	1.8	1.4
August 21	1.7	1.7	2.0	2.5	2.5	1.6
September 11	1.5	1.6	1.7	2.1	2.0	1.5
October 3	1.0	1.2	1.4	1.8	1.6	1.1
Average	1.3	1.4	1.6	2.0	2.0	1.4

Table 4.3. Nutrient additions for nutrient enrichment bioassay studies (NEB).

Sample	Concentration added ($mg.l^{-1}$)	
	P	N
Control	-	-
Low $PO_4 \cdot P$	.031	-
Medium $PO_4 \cdot P$	.093	-
High $PO_4 \cdot P$	.310	-
Low $NO_3 \cdot N$	-	.210
Medium $NO_3 \cdot N$	-	.700
High $NO_3 \cdot N$	-	2.10
Low $PO_4 \cdot P + NO_3 \cdot N$	.031	.210
Medium $PO_4 \cdot P + NO_3 \cdot N$	.093	.700
High $PO_4 \cdot P + NO_3 \cdot N$	.310	2.10

Table 4.4. Biomass and chlorophyll a concentrations ($mg.m^{-3}$) for stations sampled for bioassay experiments. NEB is the nutrient enrichment bioassay, and AT is the algal transfer bioassay.

		NEB		AT	
		August 21		September 11	
		Bio.	Chl.	Bio.	Chl.
Southern Indian Lake					
Station	10	1,635	5.6	-	-
	20	1,663	5.4	1,797	8.7
	30	1,911	1.9	-	-
	40	1,745	4.6	-	-
	50	763	4.1	1,108	3.2
	60	256	3.0	344	3.2
Isset Lake		-	-	397	1.4

Table 4.5. Carbon fixed (P), initial biomass (B), and relative activity $\frac{P}{B}$ $(\frac{P}{B})_{min}$ for incubated controls of the nutrient enrichment experiment (August 21, 1972).

Station	10	20	30	40	50	60
P (μg)	60	53	55	31	39	21
B ($\mu g.l^{-1}$)	1,635	1,663	1,911	1,745	763	256
P/B	.036	.032	.029	.018	.051	.082
Relative activity	2.0	1.8	1.6	1.0	2.8	4.6

Table 4.6. Carbon fixed (P), initial biomass (B), and relative activity for incubated controls of the algal transfer experiment (September 11, 1972).

Station	20	50	60	Isset
P (µg)	42	54	74	44
B (µg/l)	1,800	1,000	340	400
P/B	.023	.054	0.22	0.11
Relative activity	1.0	2.3	9.6	4.8

Table 4.7. Results of primary productivity measurements in Southern Indian Lake. P_{opt} is the volumetric photosynthetic rate at the light optimum. ε is the light extinction coefficient (natural logarithm), ΣΣP is the daily integral production over the depth of the euphotic zone, and assimilation is the ratio of optimum volumetric productivity to chlorophyll.

Station	Date		Chlorophyll g.l^{-1}		P_{opt} mg C.m^{-3}.hr^{-1}		ε m^{-1}		ΣΣP mg C.m^{-2}.day^{-1}		Assimilation mg C.hr^{-1}.mg chl^{-1}	
	1	2	1	2	1	2	1	2	1	2	1	2
02		29-9-73		5.4		8.4		1.3		340		1.6
06	1-9-73	29-9-73	6.2	7.2	16.1	15.8	1.2	1.4	700	600	2.6	2.2
10	1-9-73		7.0		14.8		0.96		810		2.1	
11	1-9-73		9.0		18.6		1.0		900		2.1	
12		29-9-73		6.0		11.1		0.96		610		1.9
13	1-9-73		8.6		15.7		1.2		750		1.8	
19	1-9-73	29-9-73	7.1	8.0	13.1	16.5	1.2	0.85	600	1000	1.8	2.1
79	1-9-73		5.5		14.6		1.5		510		2.7	
20	3-9-73	28-9-73	-	6.4	17.7	13.4	0.96	1.1	880	640	-	2.1
22	3-9-73	28-9-73	6.1	6.5	11.6	13.5	0.85	1.2	740	560	1.9	2.1
30	3-9-73	28-9-73	6.3	6.2	12.7	12.3	0.92	1.1	760	640	2.0	2.0
36	3-9-73		7.5		19.6		0.94		1120		2.6	
40	2-9-73	28-9-73	62	4.5	17.6	15.7	0.66	0.85	1240	910	3.4	3.5
41	2-9-73		6.5		20.5		0.84		1260		3.2	
47	2-9-73	28-9-73	6.0	7.2	18.5	16.7	0.75	1.0	1300	890	3.1	2.3
51	2-9-73		4.2		13.4		0.77		880		3.2	
50	2-9-73	28-9-73	3.7	3.6	8.1	7.8	0.62	0.77	680	530	2.2	2.2
52	2-9-73		4.8		12.5		2.2		284		2.6	
60	3-9-73	29-9-73	1.9	2.4	1.8	4.3	0.67	1.0	117	220	0.9	1.8
61	3-9-73	29-9-73	4.8	2.9	6.5	5.3	1.1	0.85	312	330	1.4	1.8

Table 4.8. Nutrient analyses performed in conjunction with productivity stations of September 1974. TDN = total dissolved nitrogen; TDP = total dissolved phosphorus; DIC = dissolved inorganic carbon; DOC = dissolved organic carbon; SN = suspended nitrogen; SP = suspended phosphorus; SC = suspended carbon; TSS = total suspended solids; nd = not detectable; - = analysis not done or result questionable.

Station	Date		TDN		NO_3-N		TDP		PO_4-P		Si		DIC	
			µg $N.1^{-1}$		µg $N.1^{-1}$		µg $P.1^{-1}$		µg $P.1^{-1}$		mg $Si.1^{-1}$		$\mu m \cdot 1^{-1}$	
	1	2	1	2	1	2	1	2	1	2	1	2	1	2
02		29-9-73		333		2		11		nd		1.16		587
06	1-9-73	29-9-73	314	353	-	2	16	11	-	nd	1.12	1.45	609	811
10	1-9-73		317		-		12		-		1.26		533	
11	1-9-73		-		-		13		-		1.09		590	
12		29-9-73		349		2		10		nd		1.26		696
13	1-9-73		233		-		13		-		1.15		522	
19	1-9-73	29-9-73	299	317	-	2	18	13	-	nd	1.33	1.26	518	592
79	1-9-73		417		-		16		-		1.17		595	
20	3-9-73	28-9-73	289	301	-	2	13	11	-	nd	1.26	1.26	516	564
22	3-9-73	28-9-73	-	250	-	1		11	-	0.5	1.31	1.45	530	558
30	3-9-73	28-9-73	94	252	-	nd	15	9	-	-	1.34	1.45	541	564
36	3-9-73		171		-		13		-		1.39		558	
40	2-9-73	28-9-73	279	267	-	3	14	14	-	1.85	1.00	0.82	601	621
41	2-9-73		313	-	-		14		-		1.33		589	
47	2-9-73	28-9-73	328	157	-	2	16	28	-	0.6	1.33	0.90	654	604
51	2-9-73		321		-		15	-	-	-	1.00	-	699	-
50	2-9-73	28-9-73	327	322	-	5	13	9	-	1.75	0.988	1.16	783	748
52	2-9-73		-		-		15	-	-		1.10		726	
60	3-9-73	29-9-73	319	243	-	1	13	13	-	nd	1.39	1.51	1281	1323
61	3-9-73	29-9-73	305	232	-	1	15	19	-	nd	1.43	1.61	1011	1018

Station	Date		DOC µm·1^{-1}		SN µg N.1^{-1}		SP µg P.1^{-1}		SC µg C.1^{-1}		TSS mg.1^{-1}	
			1	2	1	2	1	2	1	2	1	2
02		29-9-73		951		106		14		620		3
06	1-9-73	29-9-73	605	870	106	353	14	12	620	470	1	1
10	1-9-73		528		92		16		750		3	
11	1-9-73		230		82		12		530		3	
12		29-9-73		516		81		12		490		1
13	1-9-73		566		90		16		540		4	
19	1-9-73	29-9-73	463	796	99	81	16	12	520	480	1	1
79	1-9-73		949		75		11		510		2	
20	3-9-73	28-9-73	407	538	68	71	8	10	430	420	2	4
22	3-9-73	28-9-73	-	502	81	85	11	11	530	480	1	1
30	3-9-73	28-9-73	415	443	77	85	15	12	600	540	2	1
36	3-9-73		533		97		16		570		2	
40	2-9-73	28-9-73	507	797	53	79	10	14	420	560	1	2
41	2-9-73		441		82		12		488		2	
47	2-9-73	28-9-73	479	686	93	91	16	12	560	610	1	1
51	2-9-73		416	-	81		11		550		1	
50	2-9-73	28-9-73	522	686	73	98	9	10	460	610	1	1
52	2-9-73		859		71		12		560		2	
60	3-9-73	29-9-73	462	538	38	42	5	5	340	280	1	1
61	3-9-73	29-9-73	477	708	71	66	9	7	450	370	2	1

Table 4.9. Average seasonal chlorophyll (June 21 to Octobe
and average seasonal biomass at 0.5 m depth.

Station	Chlorophyll ($mg.m^{-3}$)	Biomass ($mg.m^{-3}$)
10	4.2	1,075
20	5.1	1,254
30	5.0	1,140
40	2.3	1,383
50	2.5	1,018
60	2.8	336

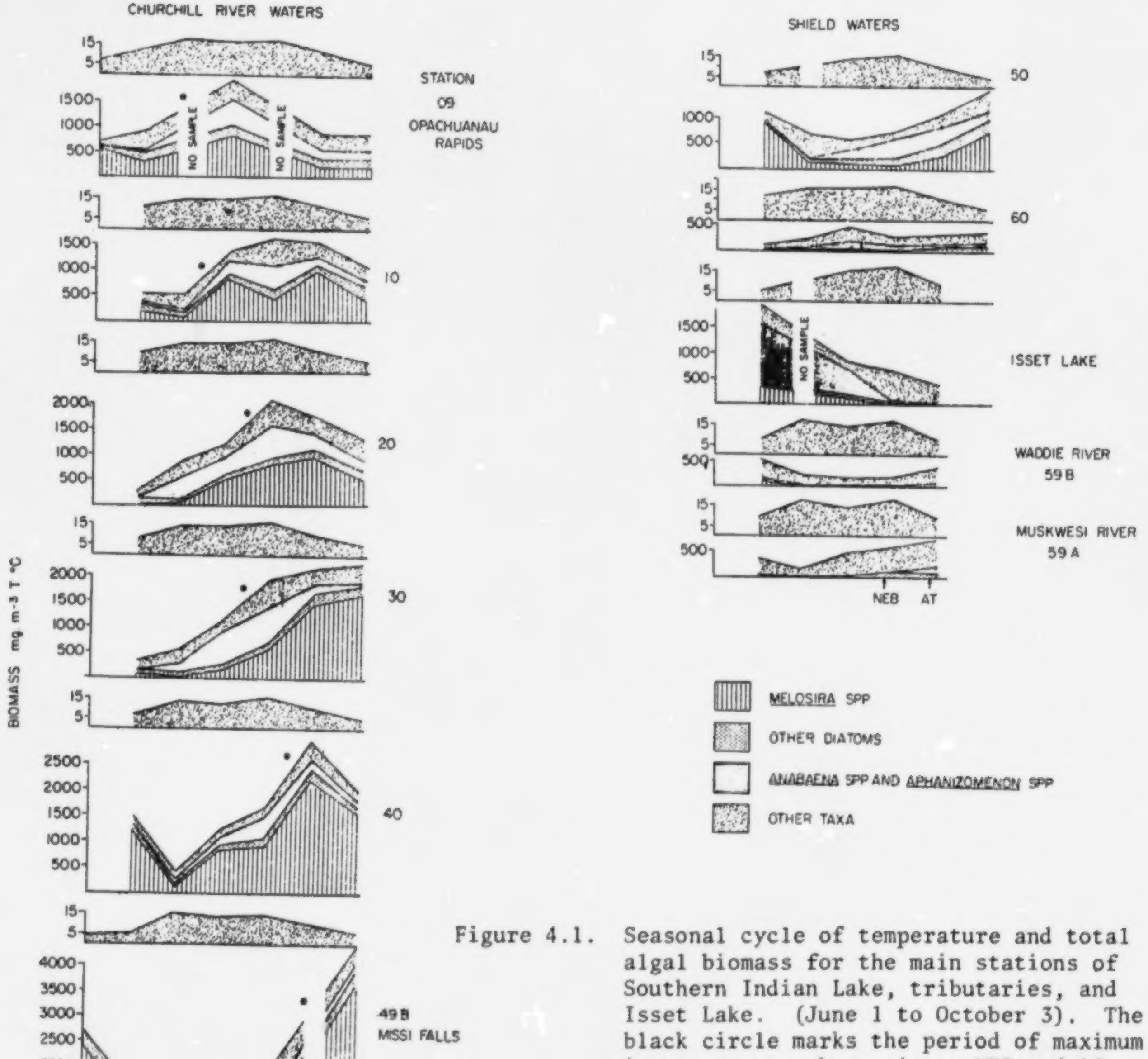
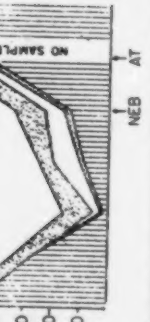


Figure 4.1. Seasonal cycle of temperature and total algal biomass for the main stations of Southern Indian Lake, tributaries, and Isset Lake. (June 1 to October 3). The black circle marks the period of maximum

indicate samples taken for bioassay
experiments.



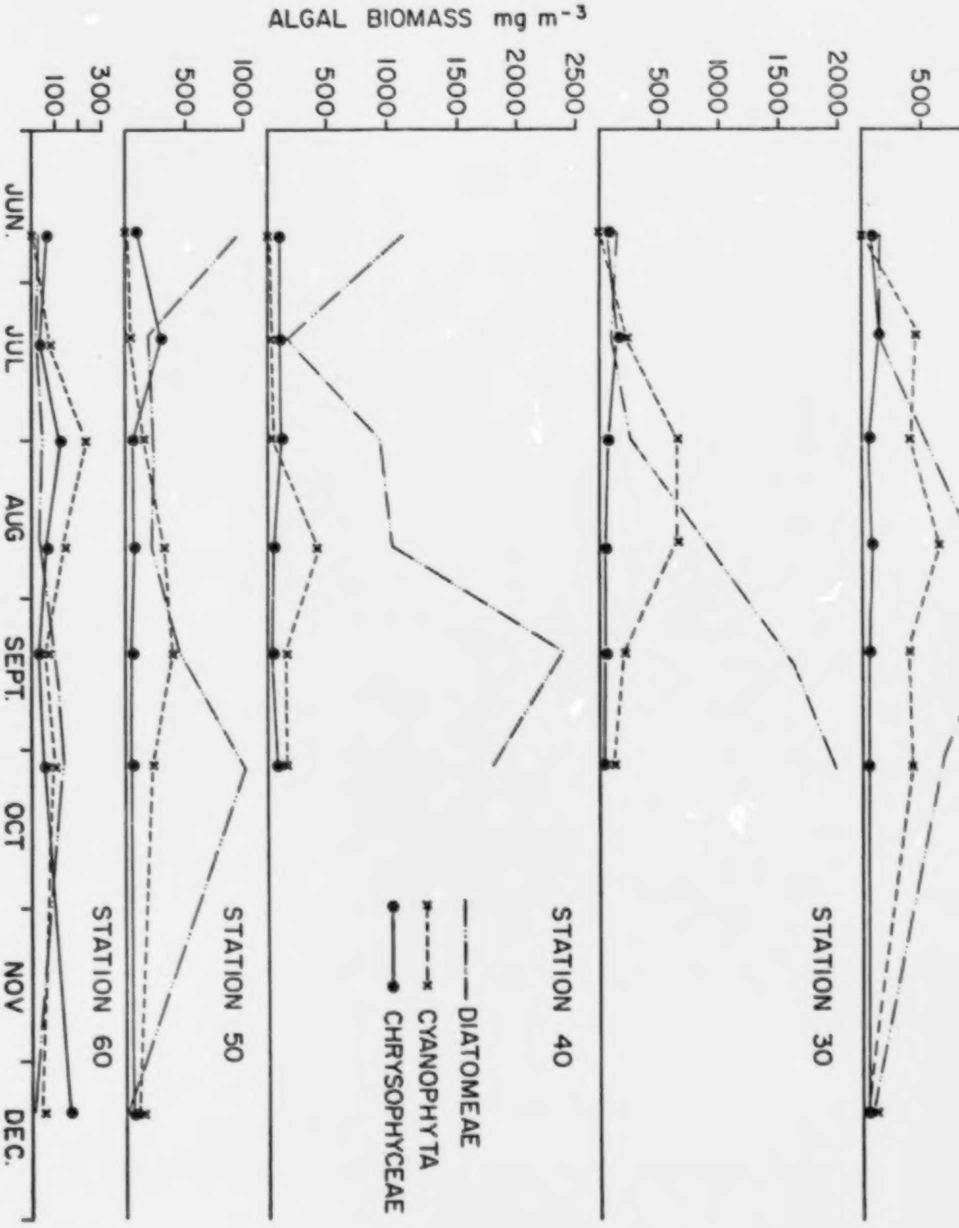


Figure 4.2. Seasonal cycle of the predominant algal groups for m
of Southern Indian Lake.

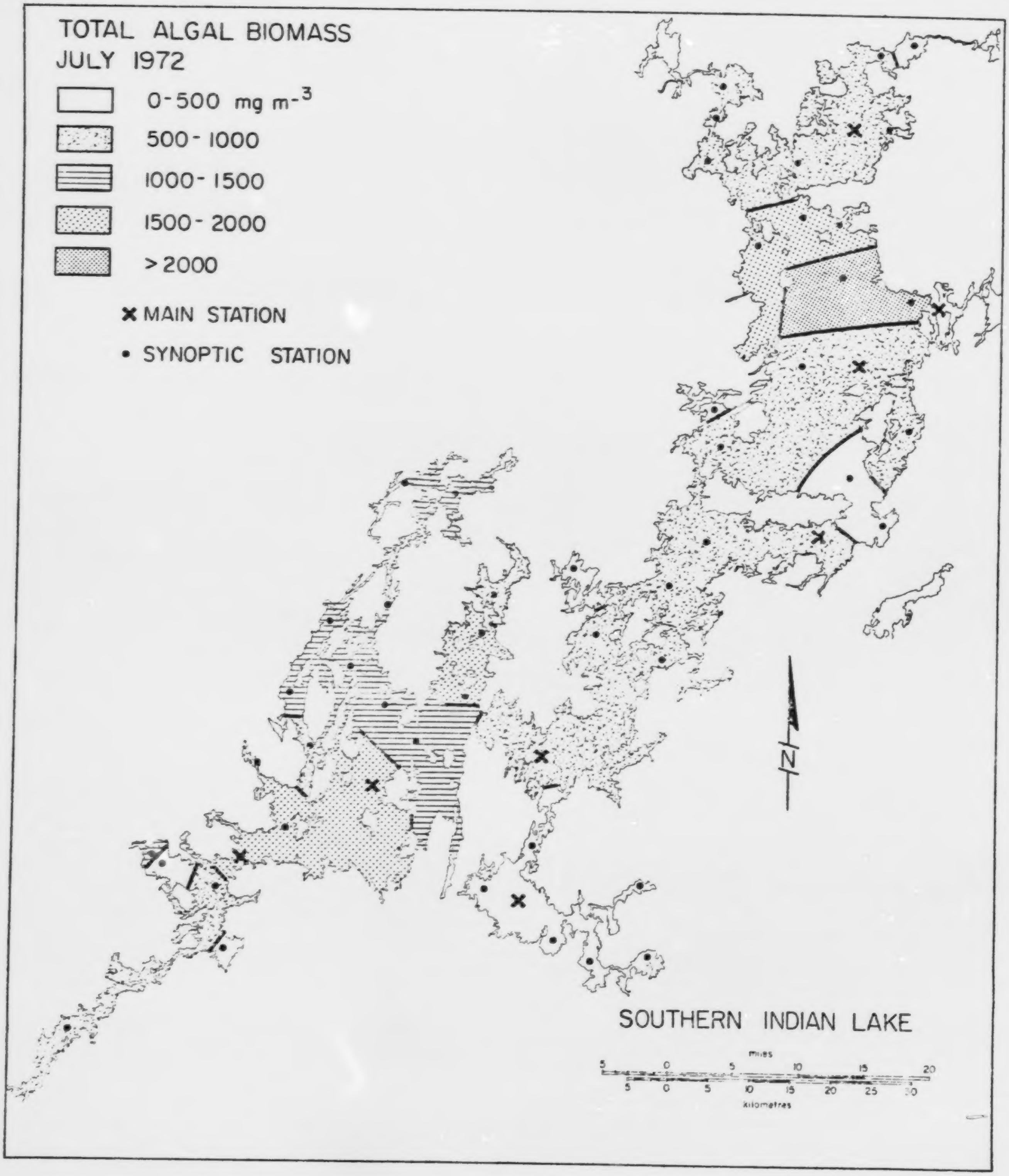

TOTAL ALGAL BIOMASS
JULY 1972
0-500 mg m-3
500-1000
1000-1500
1500-2000
>2000
MAIN STATION
SYNOPTIC STATION
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres
N

Figure 4.3. Horizontal distribution of total algal biomass in July.

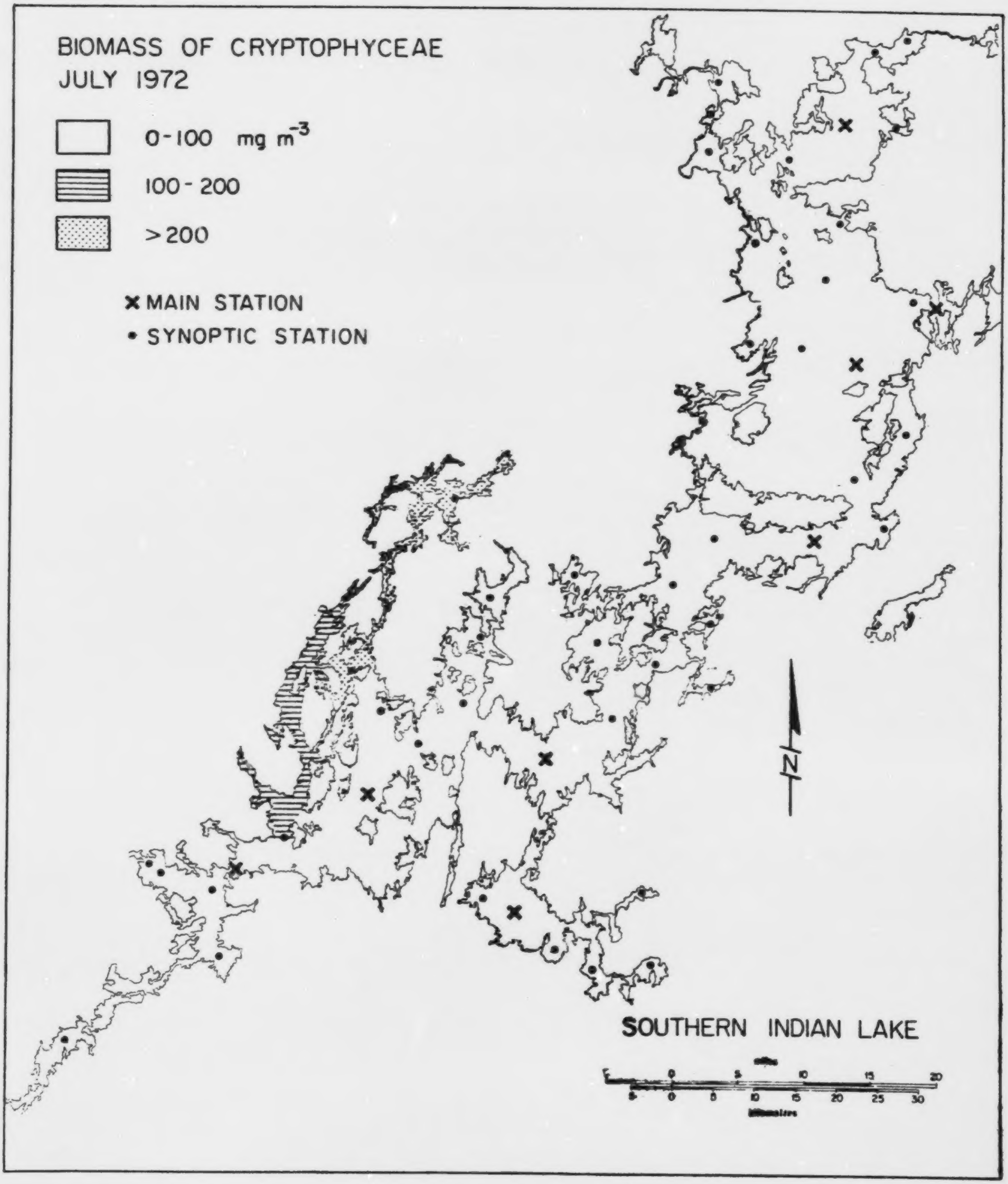

BIOMASS OF CRYPTOPHYCEAE
JULY 1972
0-100 mg m^{-3}
100-200
>200
✖ MAIN STATION
• SYNOPTIC STATION
N
SOUTHERN INDIAN LAKE
5 0 5 10 15 20
5 0 5 10 15 20 25 30

Figure 4.4. Horizontal distribution of Cryptophyceae in July.

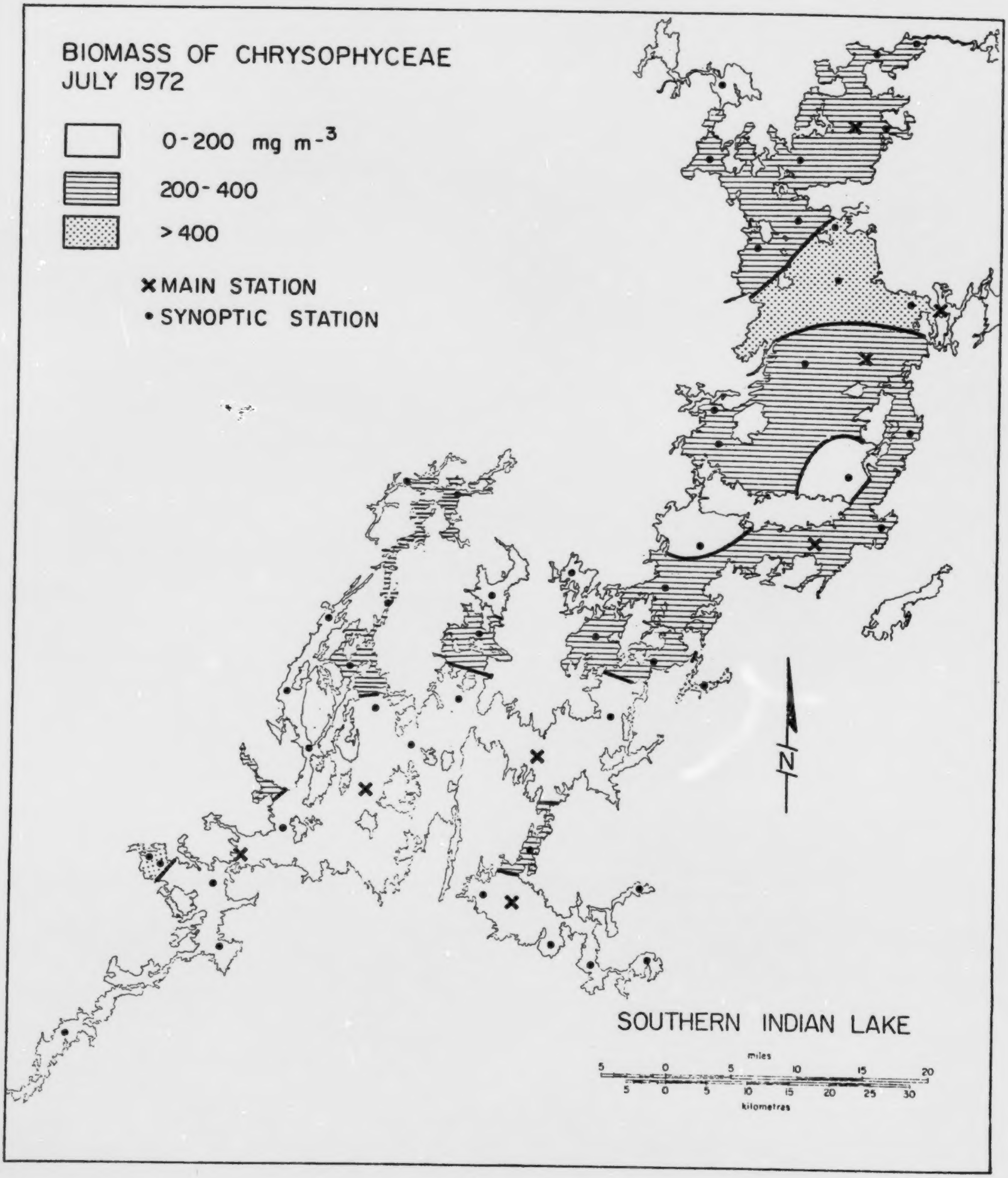

BIOMASS OF CHRYSOPHYCEAE
JULY 1972
0-200 mg m-3
200-400
>400
× MAIN STATION
• SYNOPTIC STATION
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

Figure 4.5. Horizontal distribution of Chrysophyceae in July.

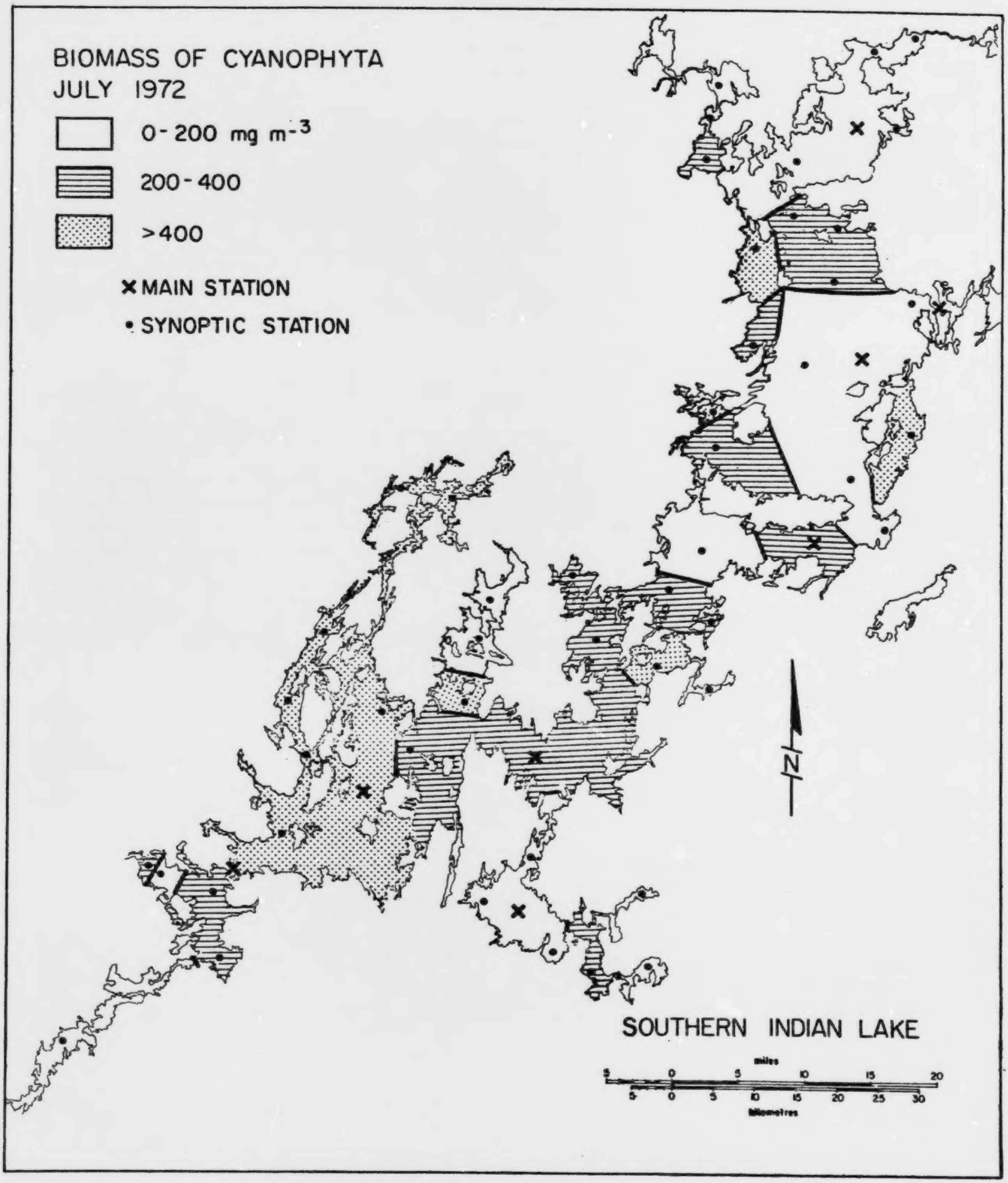

BIOMASS OF CYANOPHYTA
JULY 1972
0-200 mg m-3
200-400
>400
× MAIN STATION
• SYNOPTIC STATION
N
SOUTHERN INDIAN LAKE
miles
5
0
5
10
15
20
5
0
5
10
15
20
25
30
kilometres

Figure 4.6. Horizontal distribution of Cyanophyta in July.

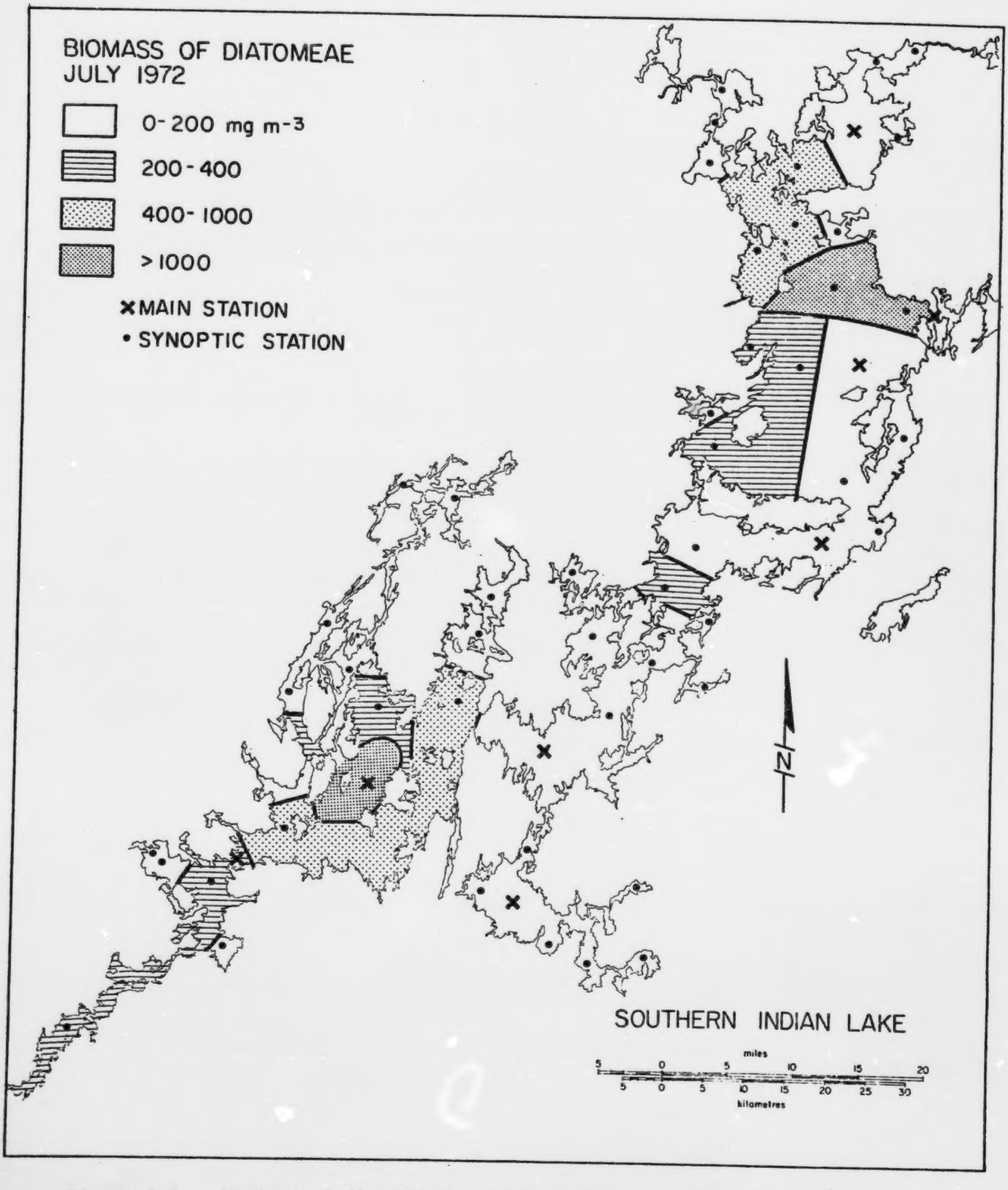

BIOMASS OF DIATOMEAE
JULY 1972
0-200 mg m-3
200-400
400-1000
>1000
×MAIN STATION
• SYNOPTIC STATION
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

Figure 4.7. Horizontal distribution of Diatomeae in July.

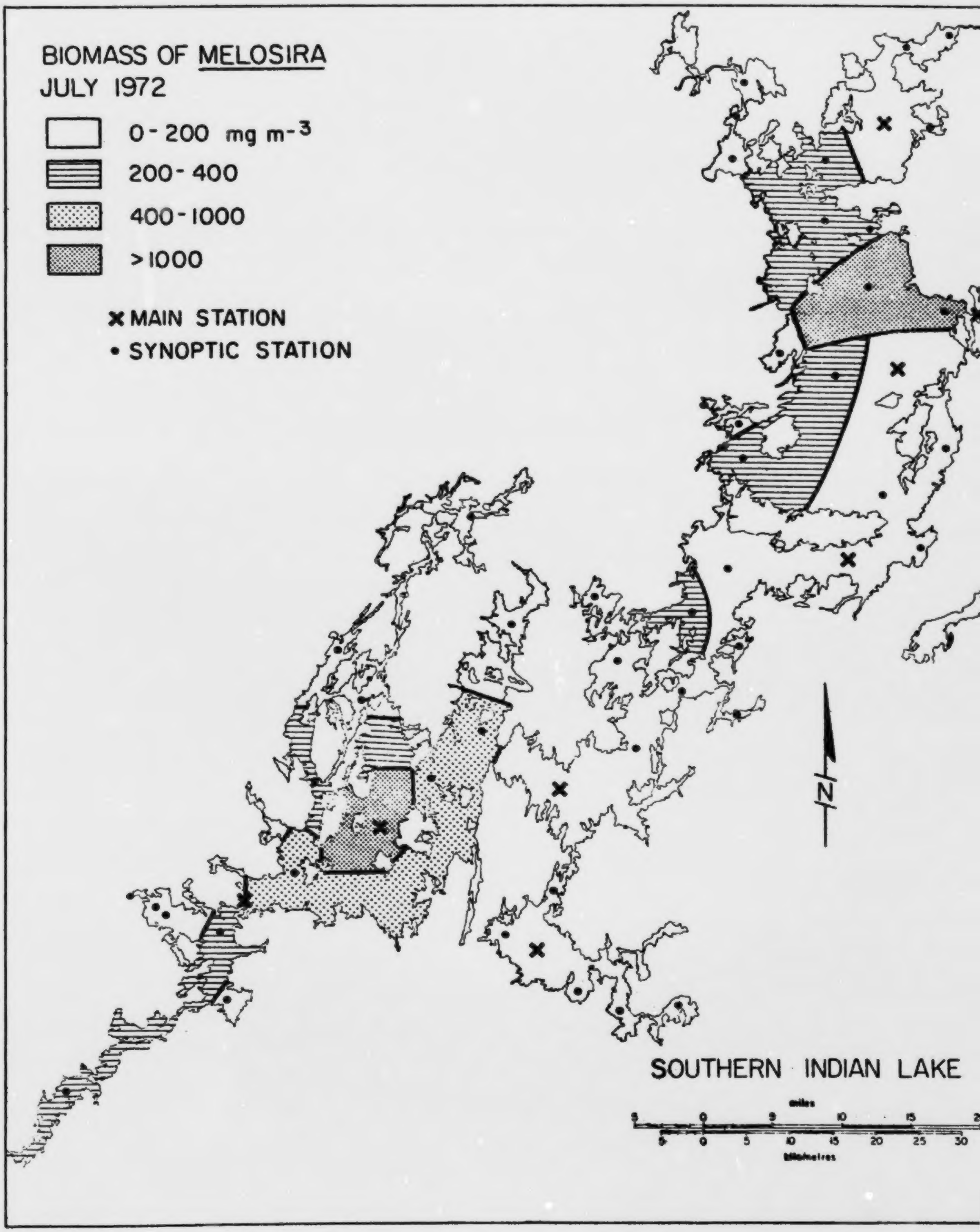

BIOMASS OF MELOSIRA
JULY 1972
0-200 mg m-3
200-400
400-1000
>1000
× MAIN STATION
• SYNOPTIC STATION
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15
5 0 5 10 15 20 25 30
kilometres

Figure 4.8. Horizontal distribution of Melosira spp. in July.

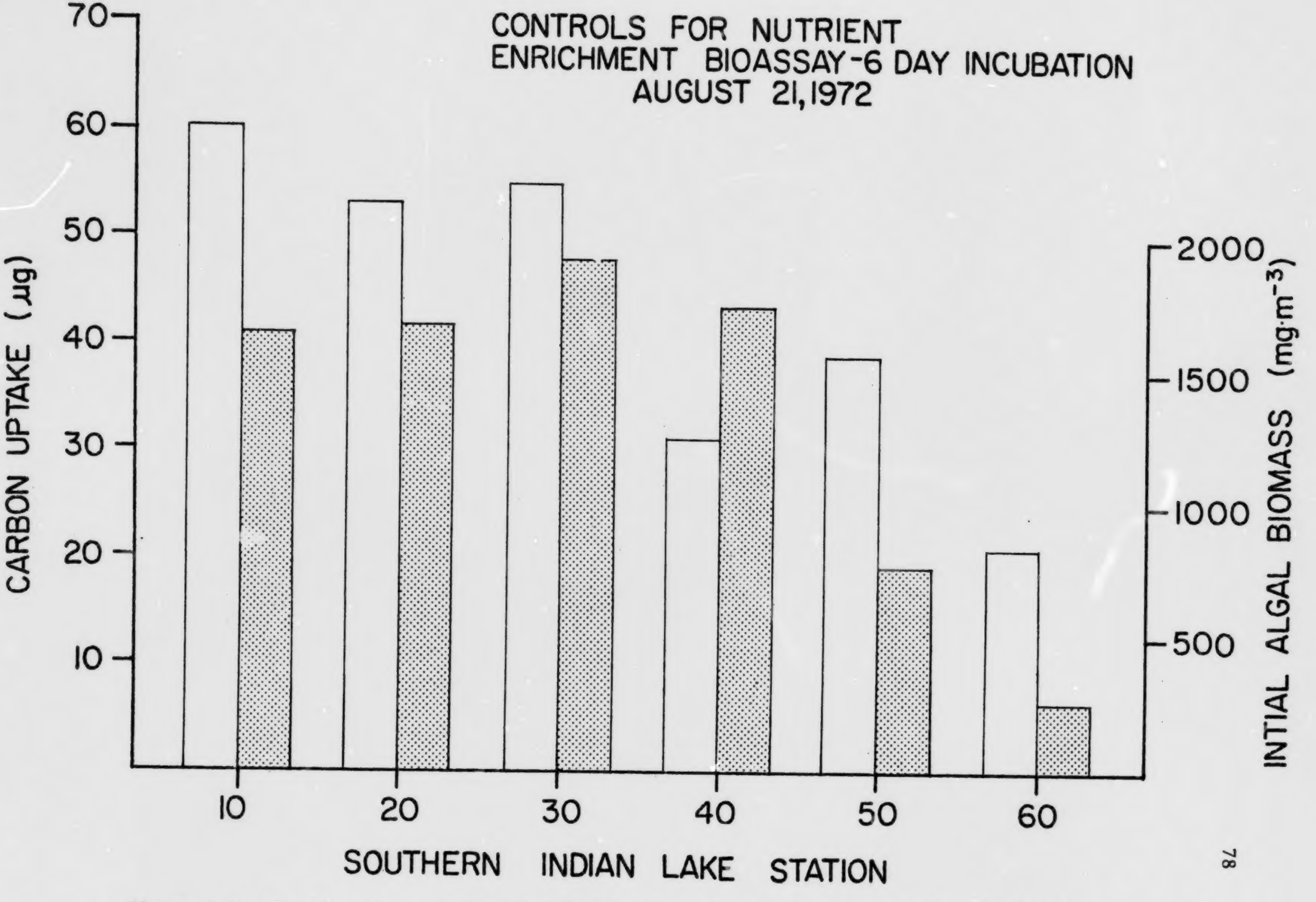


Figure 4.9. Total carbon uptake and initial algal biomass for control flasks of the nutrient enrichment bioassay.

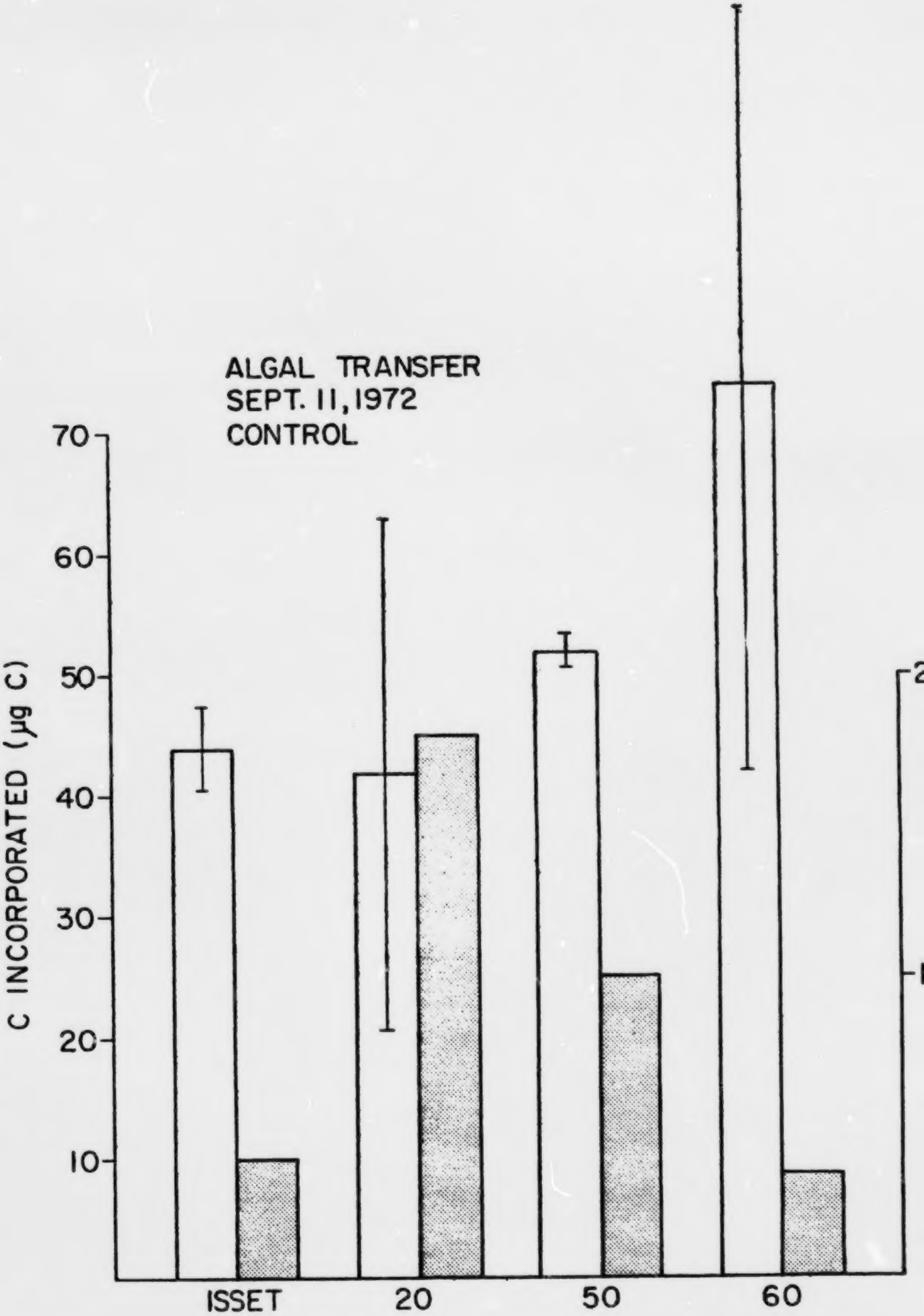


Figure 4.10. Carbon uptake and initial algal biomass for control flasks of the algal transfer experiment.

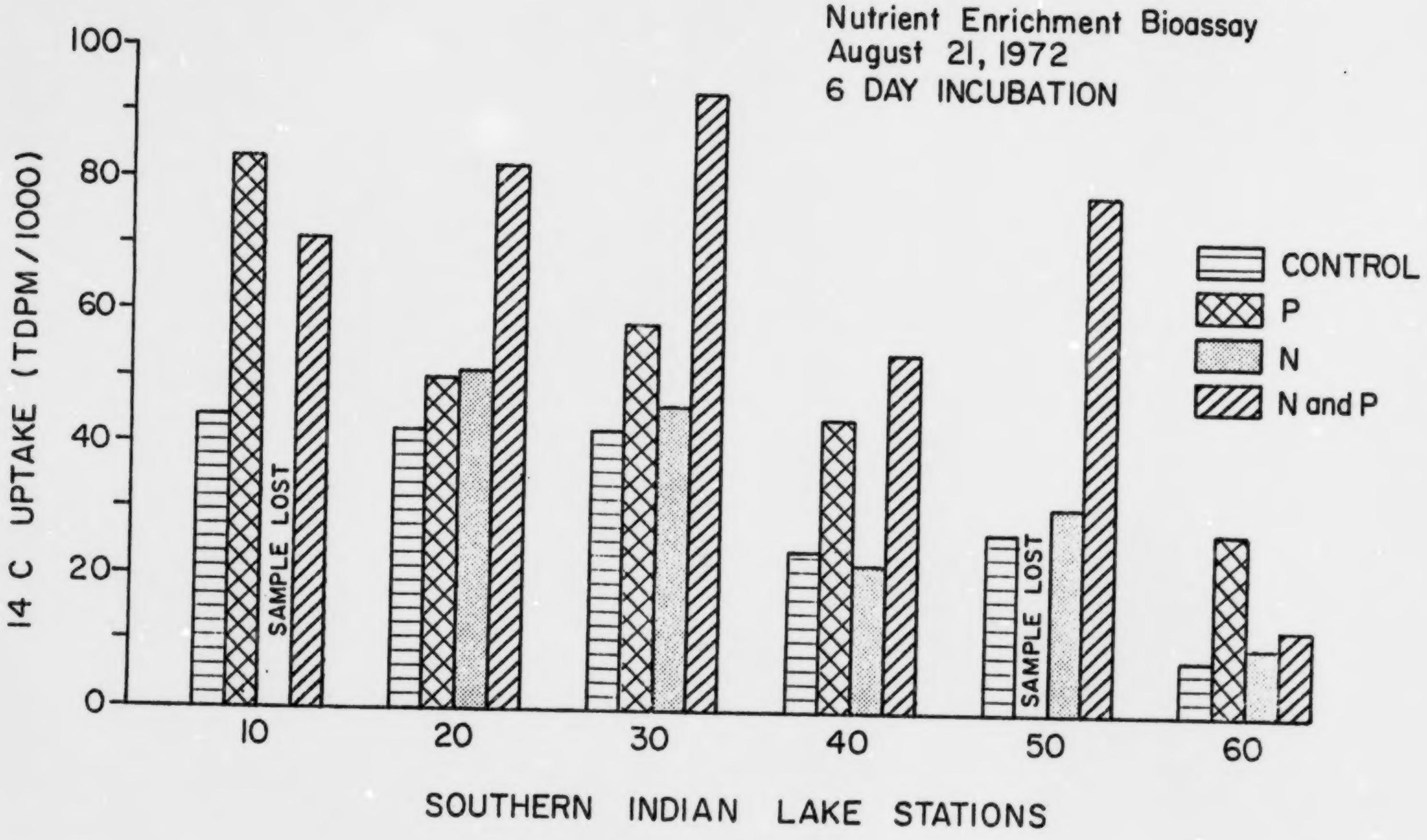


Figure 4.11. Results of nutrient enrichment bioassay.

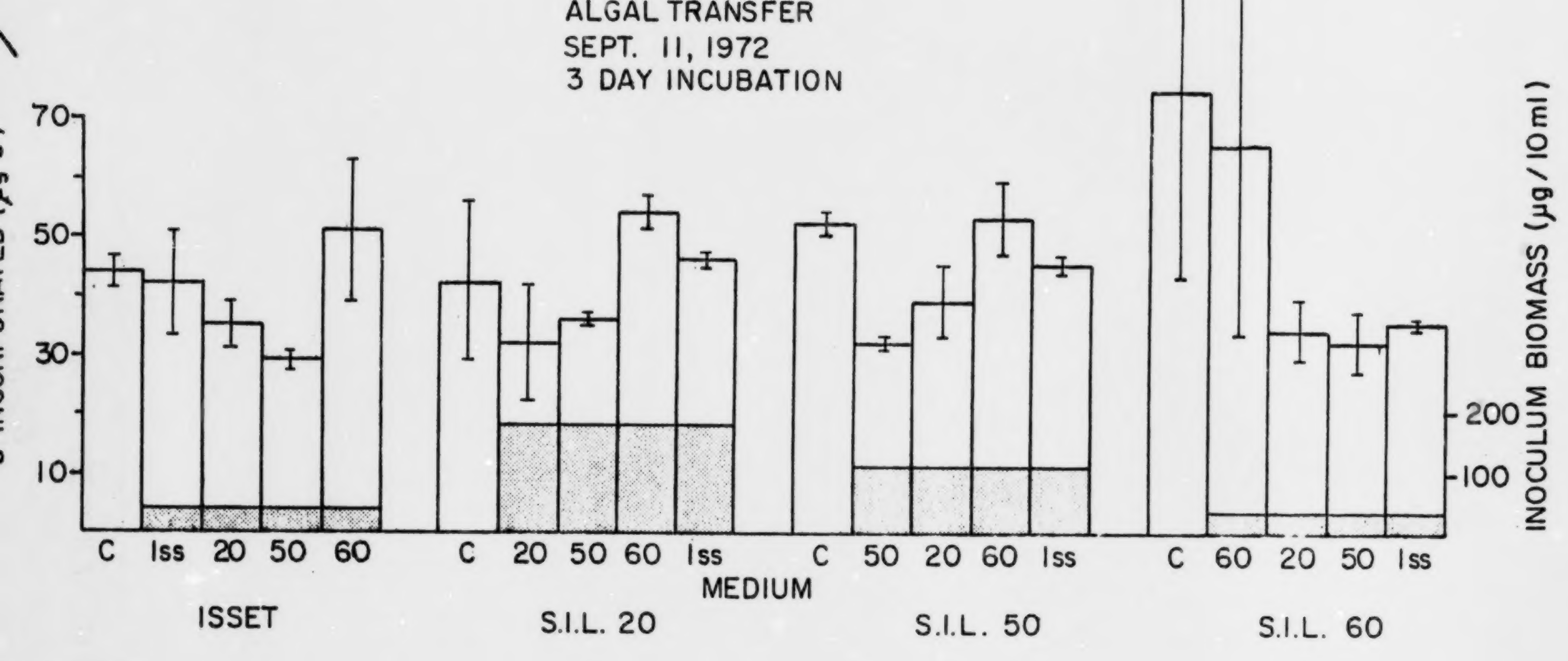
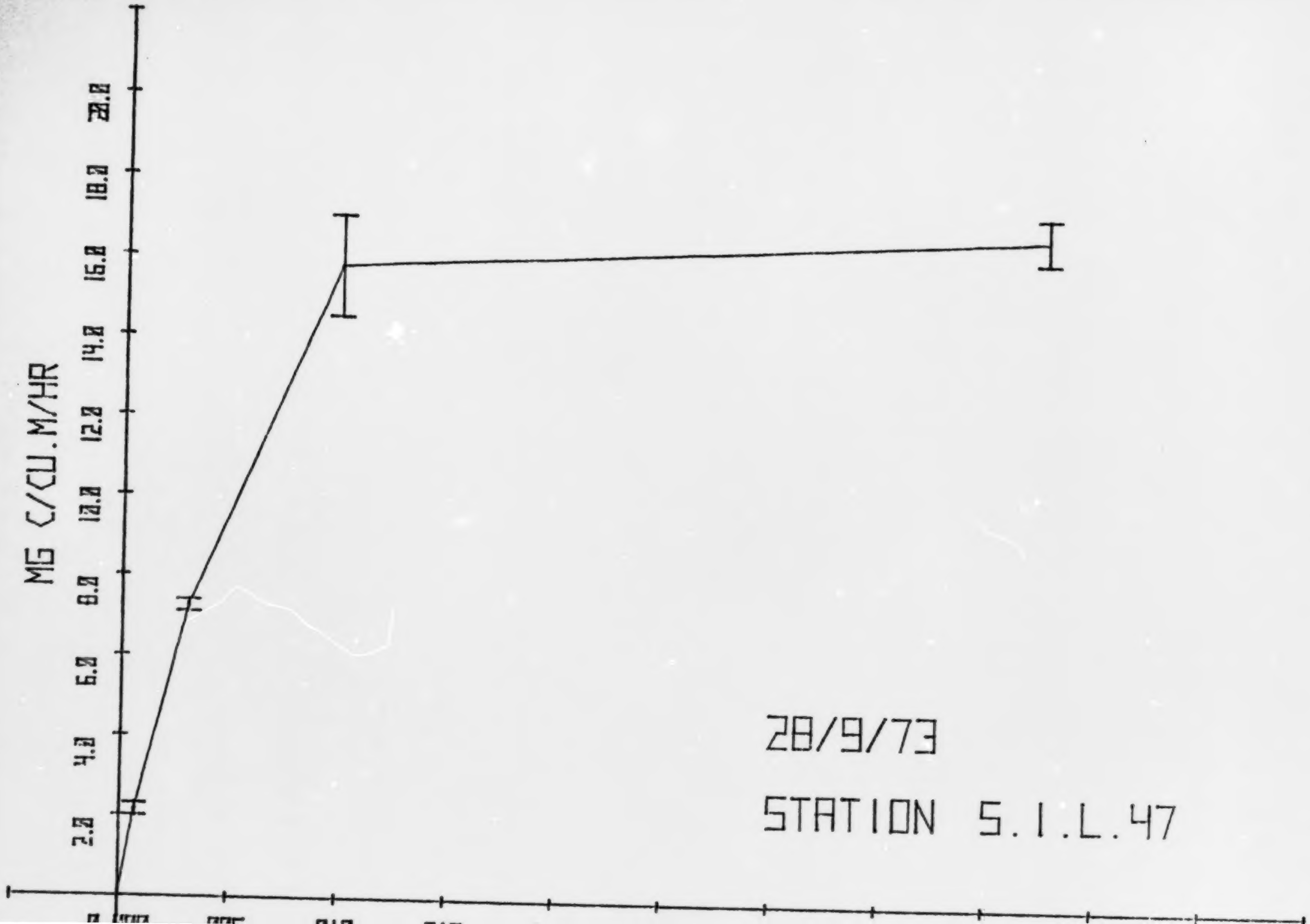
ALGAL TRANSFER
SEPT. 11, 1972
3 DAY INCUBATION
70
50
30
10
C
Iss
20
50
60
C
20
50
60
Iss
C
50
20
60
Iss
C
60
20
50
Iss
MEDIUM
ISSET
S.I.L. 20
S.I.L. 50
S.I.L. 60
200
100
INOCULUM BIOMASS (μg / 10ml)

Figure 4.12. Results of algal transfer bioassay. Range of replicate flasks indicated.



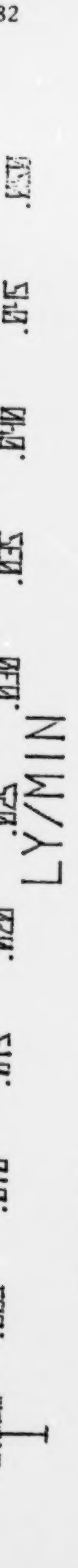


Figure 4.13. Typical light response curve.

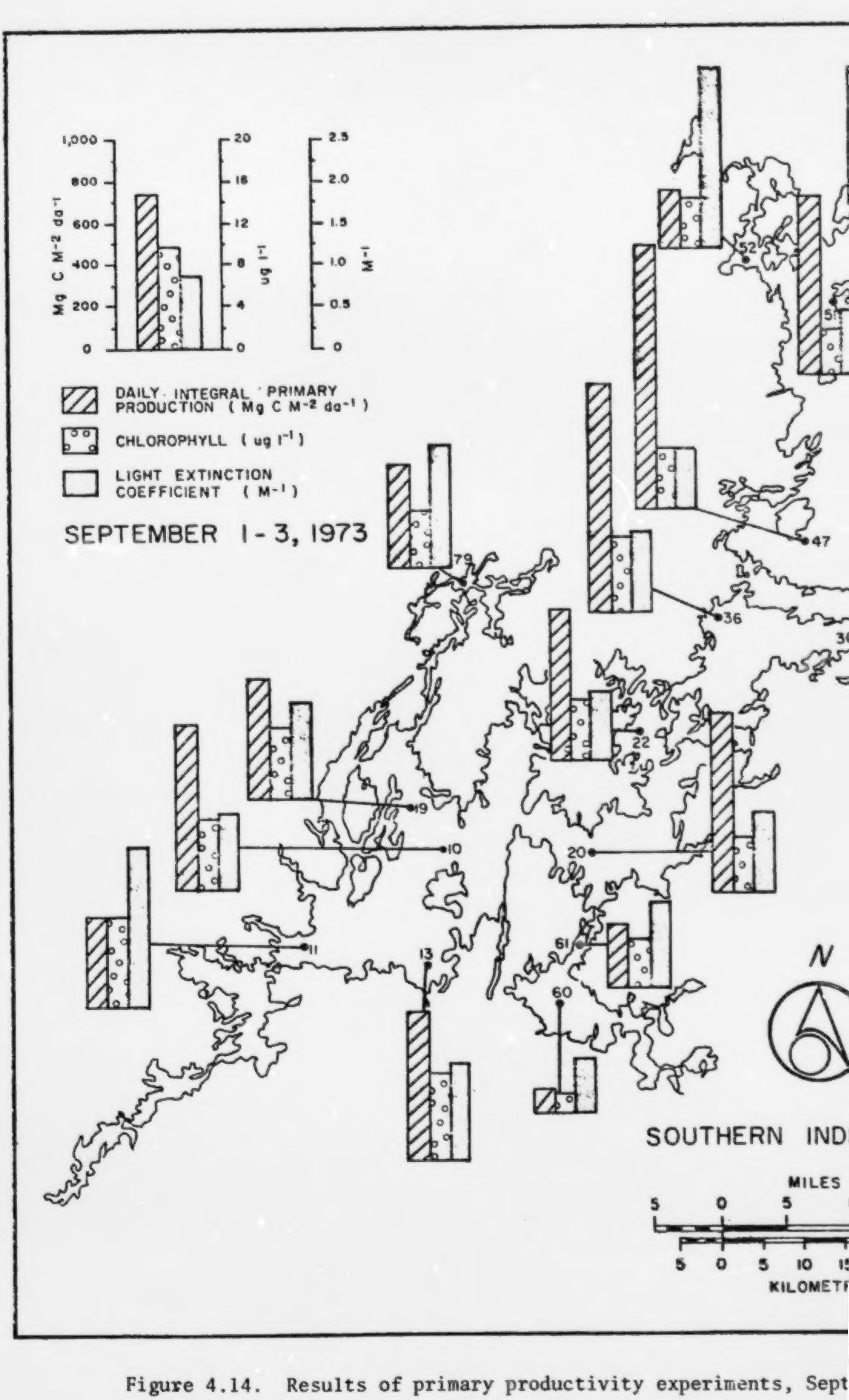
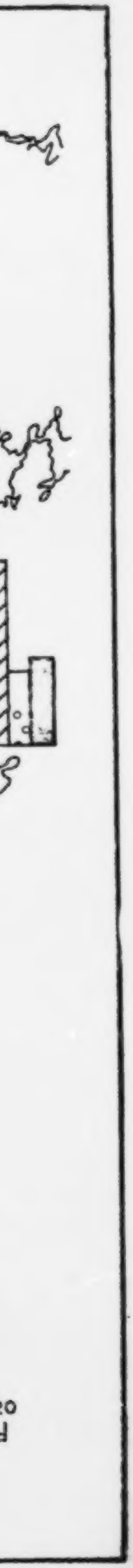

1,000
800
600
400
200
0
Mg C M-2 da-1
20
16
12
8
4
0
ug l-1
2.5
2.0
1.5
1.0
0.5
0
M-1
DAILY INTEGRAL PRIMARY PRODUCTION (Mg C M-2 da-1)
CHLOROPHYLL (ug l-1)
LIGHT EXTINCTION COEFFICIENT (M-1)
SEPTEMBER 1-3, 1973
52
51
47
36
30
79
22
19
10
20
11
13
61
60
N
SOUTHERN IND
MILES
5
0
5
5
0
5
10
15
KILOMETR

Figure 4.14. Results of primary productivity experiments, Sept



973.

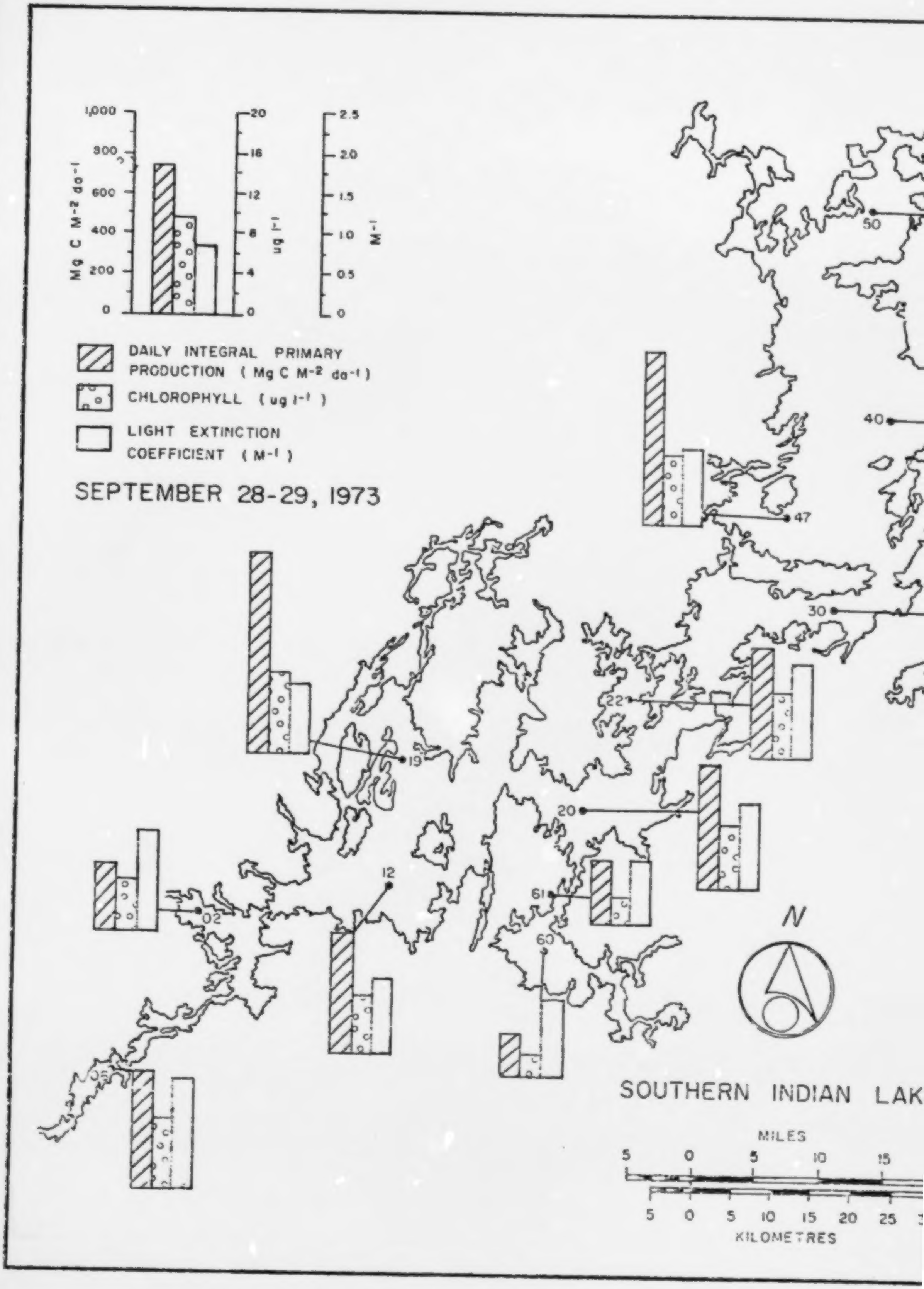
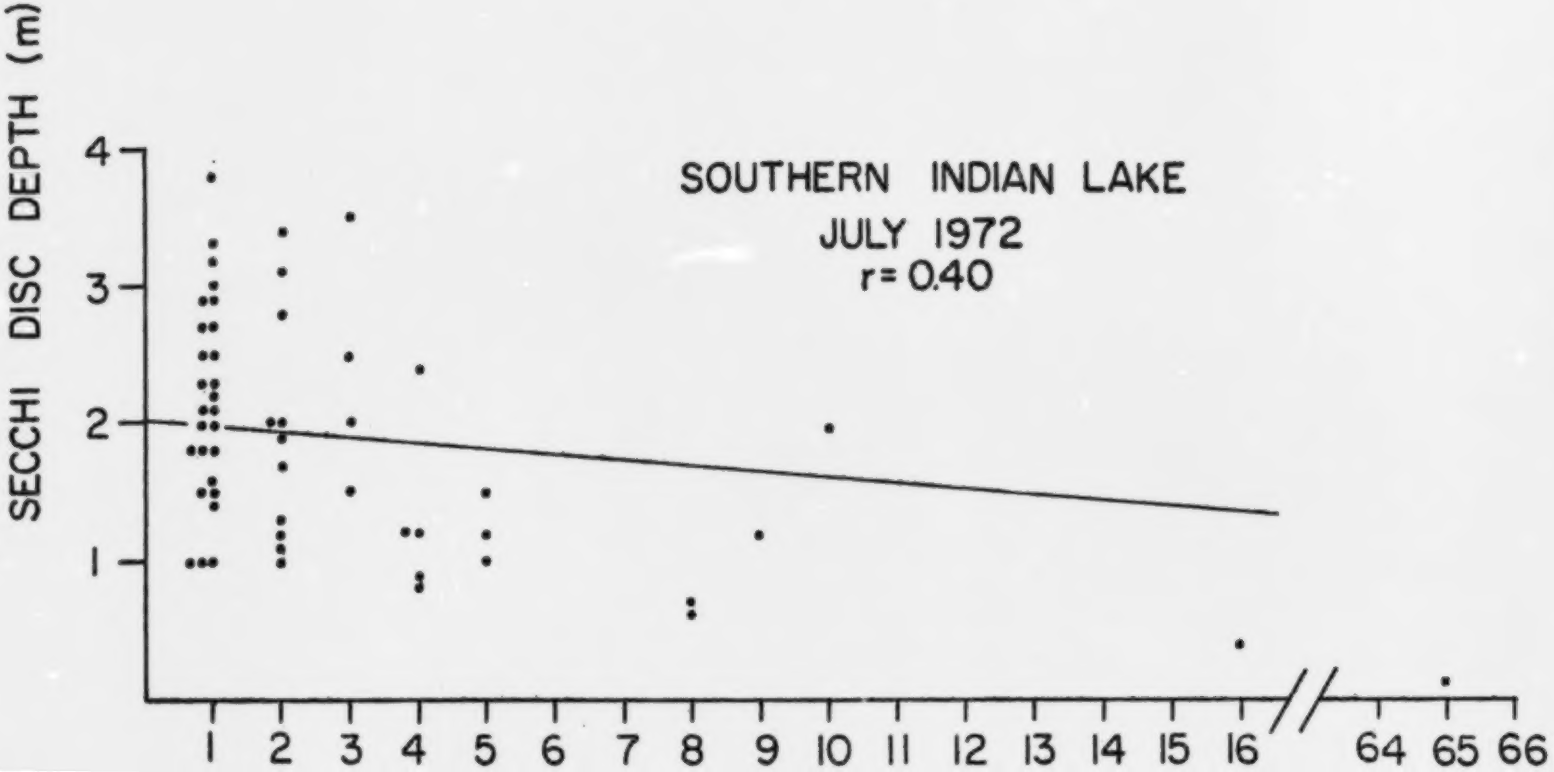

1,000
800
600
400
200
0
Mg C M-2 da-1
20
16
12
8
4
0
ug l-1
2.5
2.0
1.5
1.0
0.5
0
M-1
DAILY INTEGRAL PRIMARY PRODUCTION (Mg C M-2 da-1)
CHLOROPHYLL (ug l-1)
LIGHT EXTINCTION COEFFICIENT (M-1)
SEPTEMBER 28-29, 1973
50
40
47
30
19
22
20
12
02
61
60
05
N
SOUTHERN INDIAN LAK
MILES
5
0
5
10
15
5
0
5
10
15
20
25
KILOMETRES

Figure 4.15. Results of primary productivity experiments, September 28


SOUTHERN INDIAN LAKE
JULY 1972
r= 0.40
SECCHI DISC DEPTH (m)
1
2
3
4
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
64
65
66

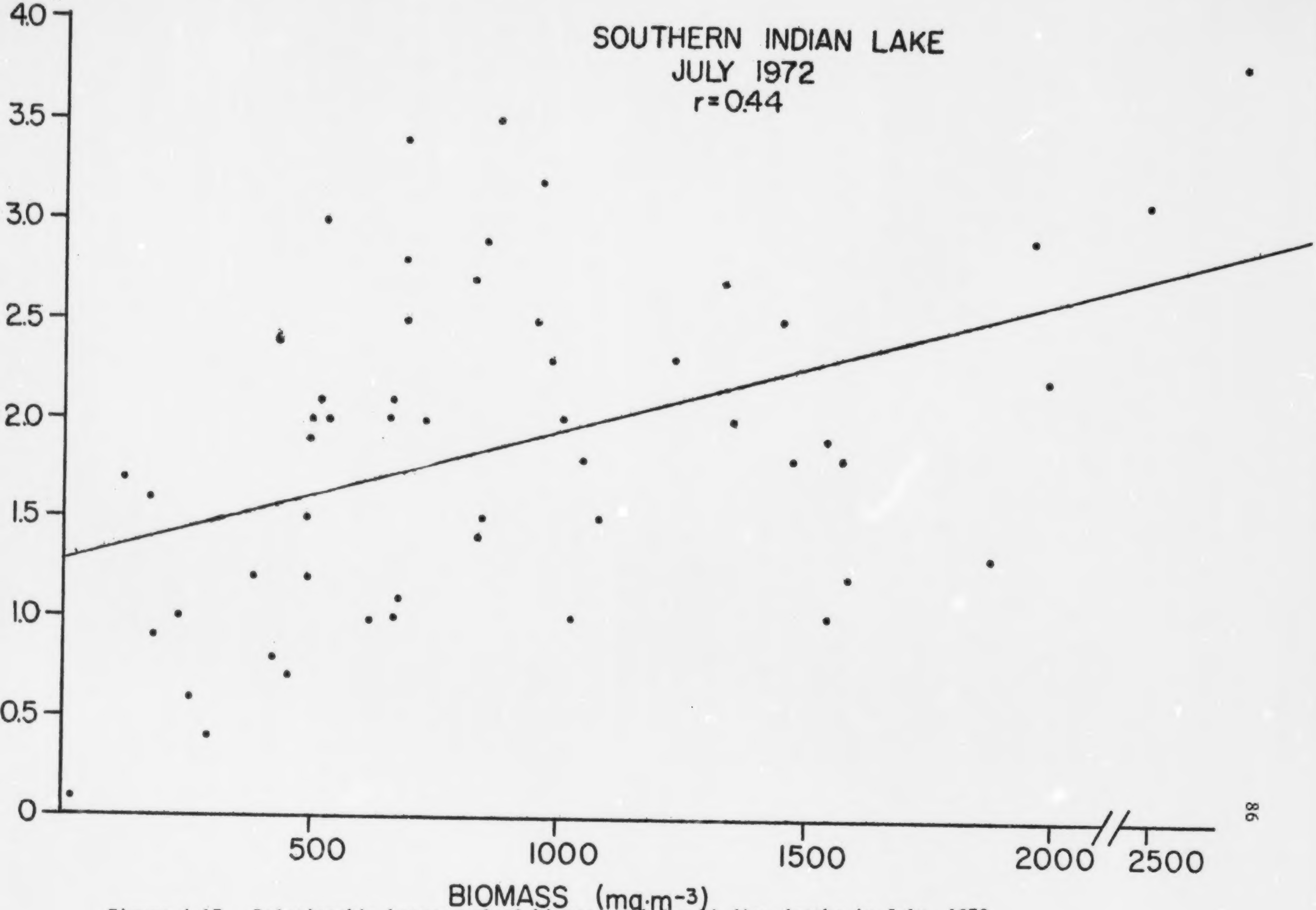


Figure 4.17. Relationship between algal biomass and Secchi disc depths in July, 1972.

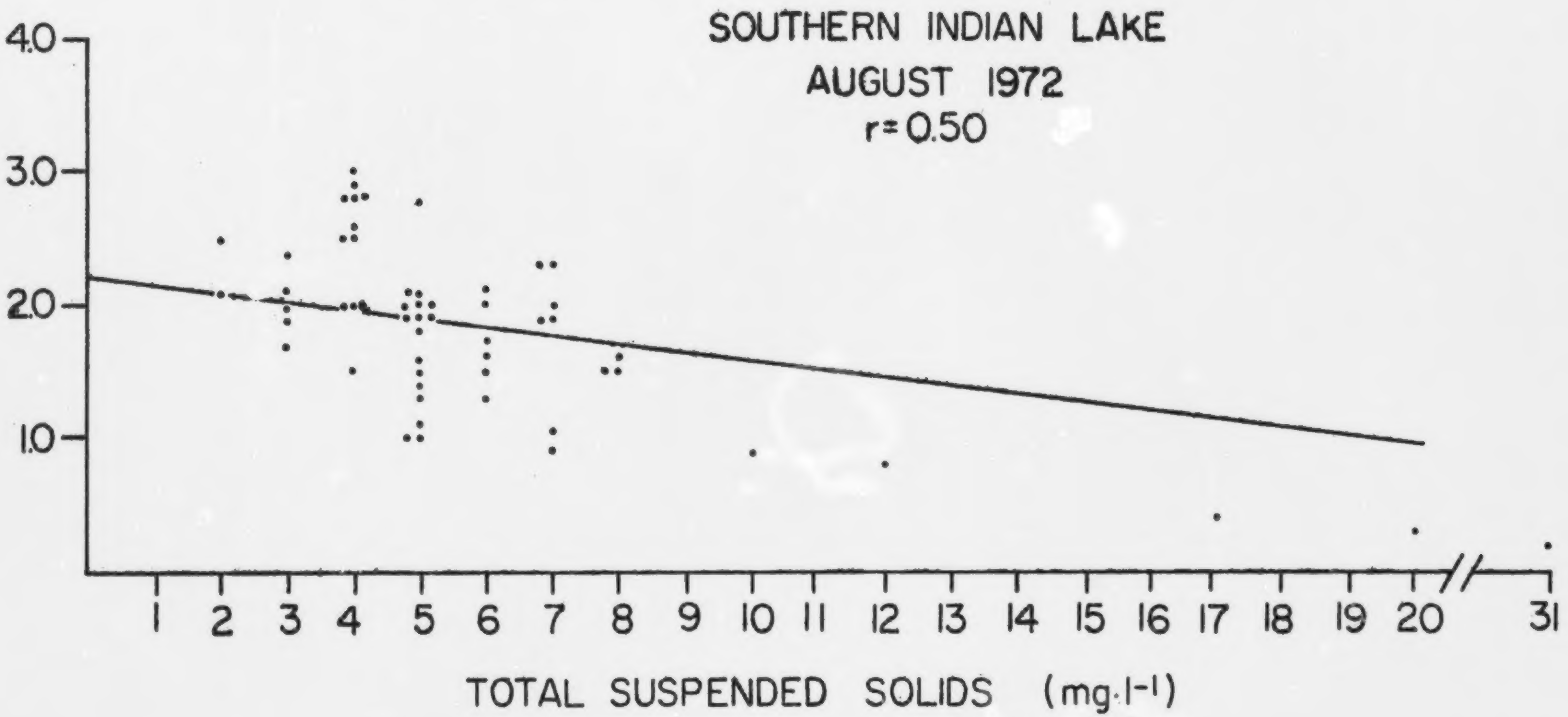


Figure 4.18. Relationship between total suspended solids and Secchi disc depths in August, 1972.

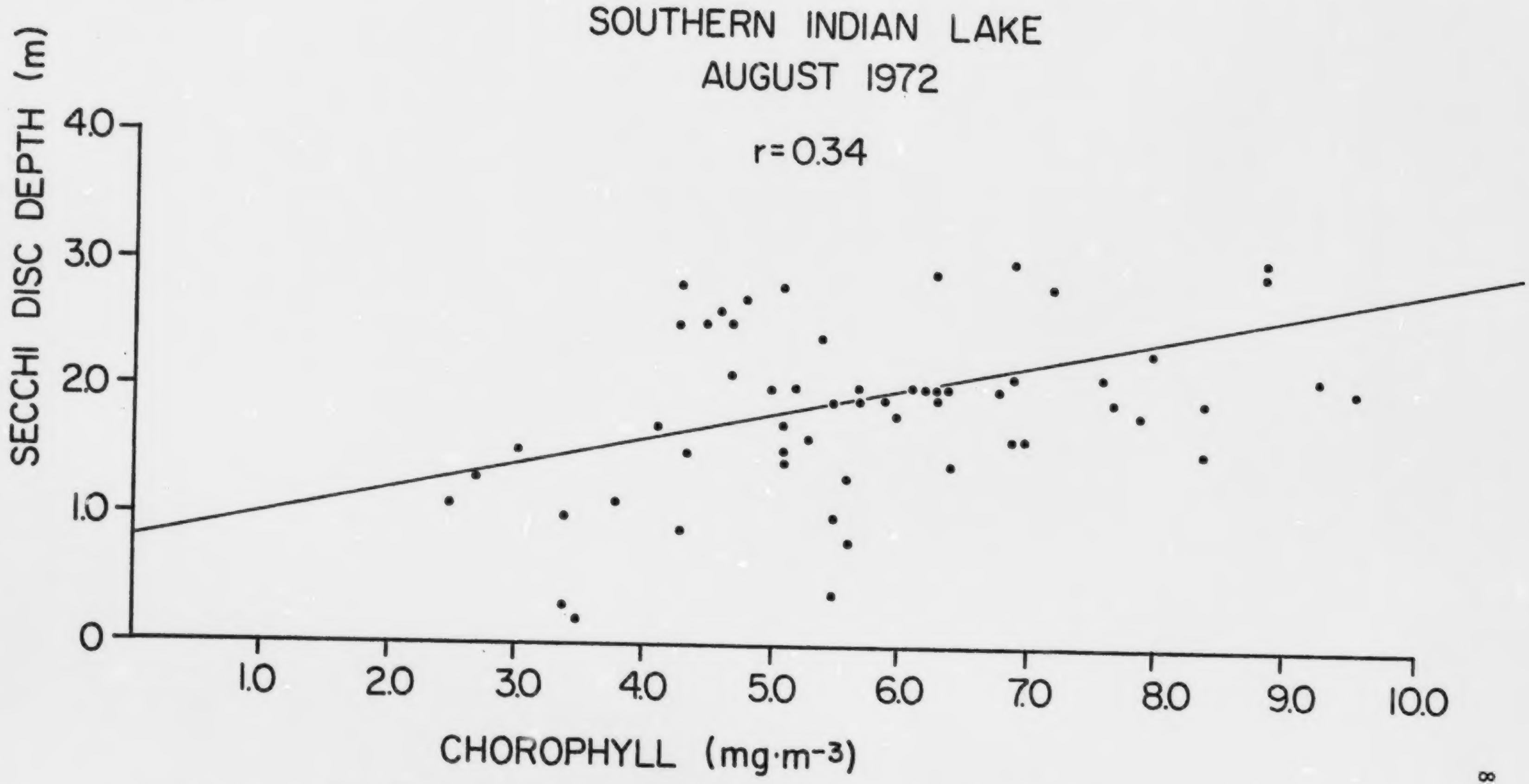


Figure 4.19. Relationship between chlorophyll and Secchi disc depths in August, 1972.

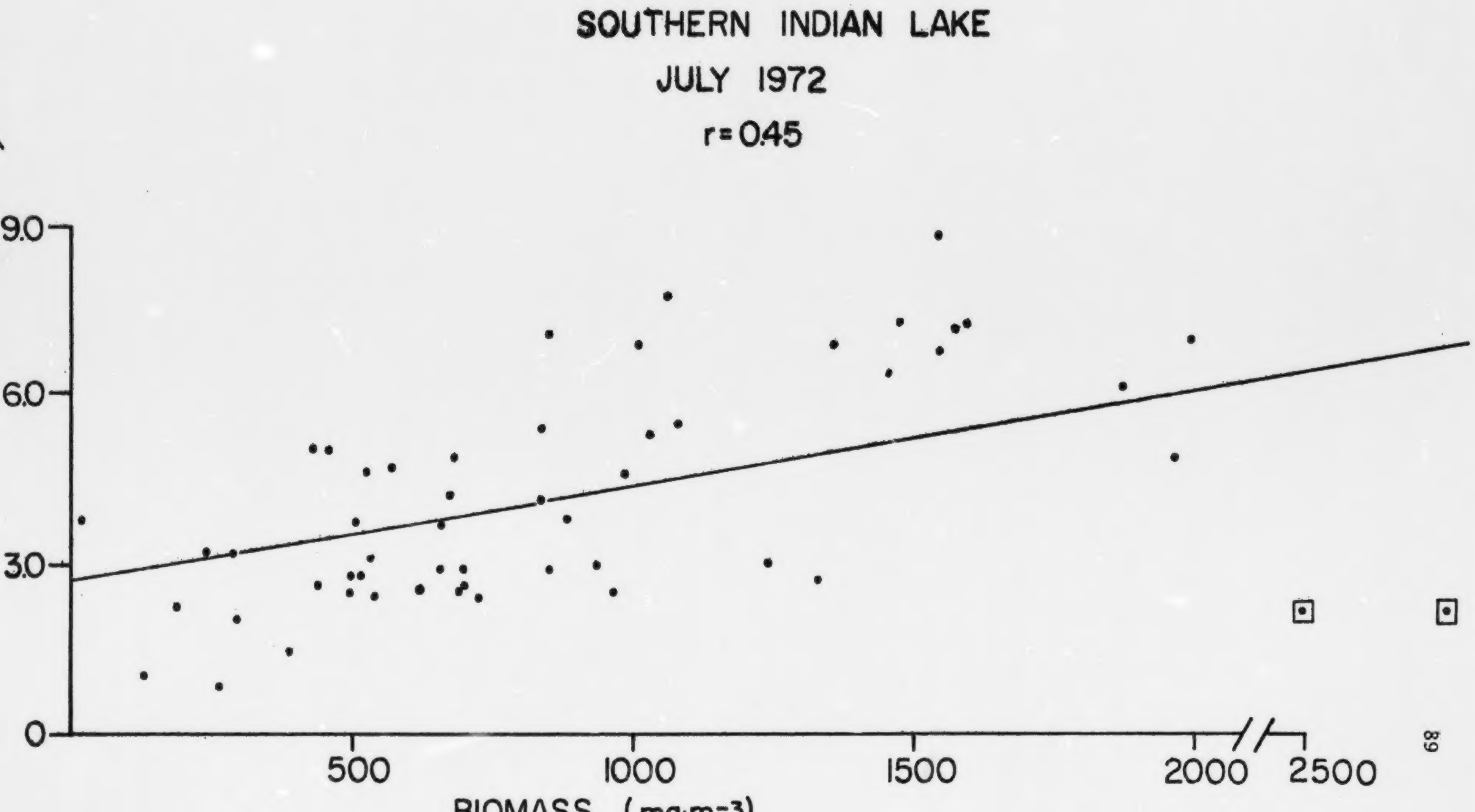


Figure 4.20. Relationship between algal biomass and chlorophyll in July, 1972.

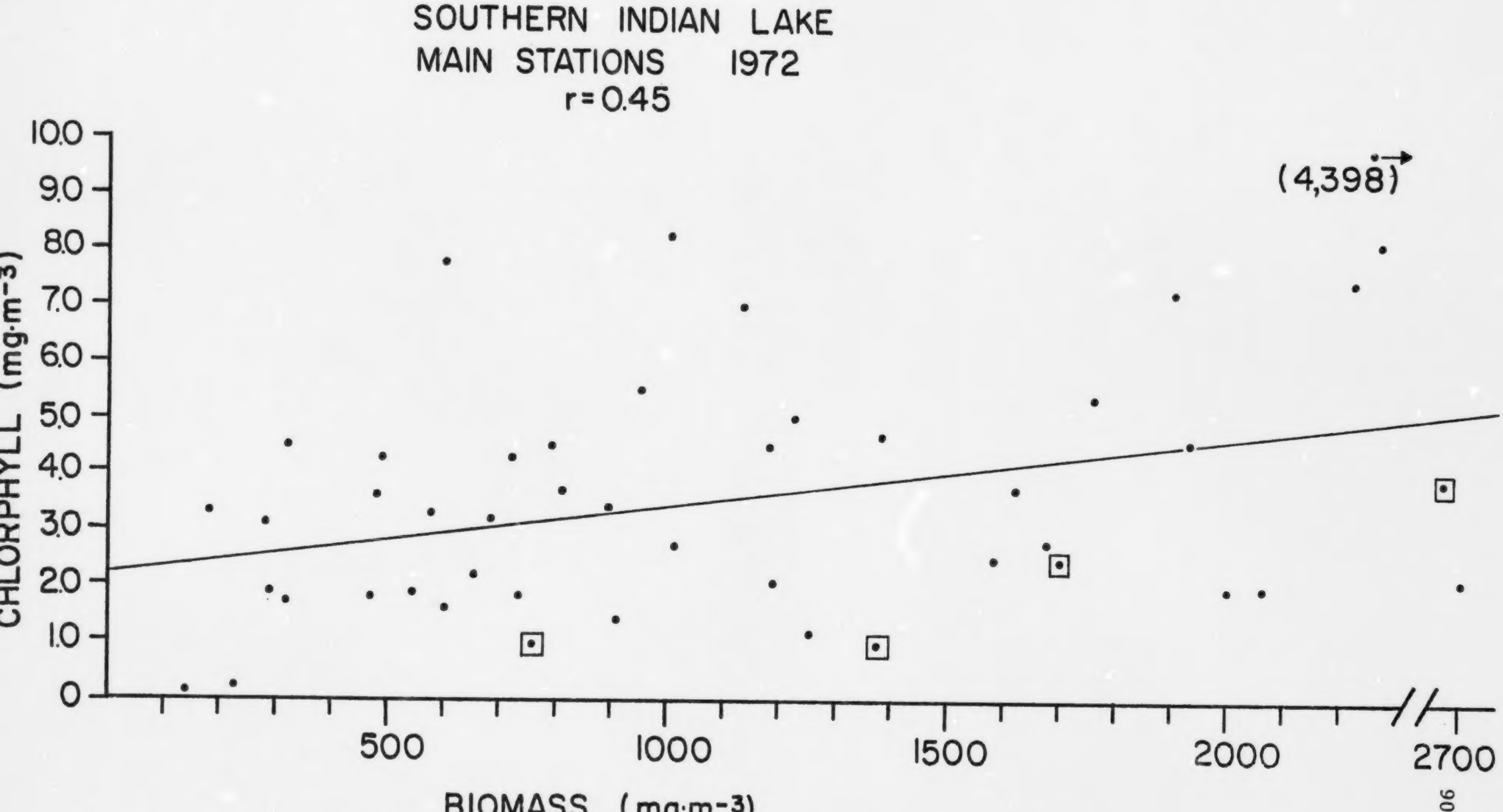


Figure 4.21. Relationship between algal biomass and chlorophyll for the main stations through the 1972 season (June-October).

APPENDIX 5 - VOL. 1 - F.

ZOOPLANKTON STUDY IN SOUTHERN INDIAN

ZOOPLANKTON STUDY
IN
SOUTHERN INDIAN LAKE

by

K. PATALAS and A. SALKI
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
February, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

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5.1. INTRODUCTION

Zooplankton study was undertaken in 1972 as part of a collecti effort to characterize the present chemical and biological condition of Southern Indian Lake and to gather data necessary to predict and assess changes following the diversion of the Churchill River system.

Semi-synoptic data were collected between August 25 and Septem 1, 1972 from 57 stations distributed all over the lake and representi both open-water regions and more or less isolated bays. Total vertic hauls were made in each station from the bottom to the surface using twin nets each with a mouth diameter of 25 cm and pore openings of 77 Simultaneously, temperature measurements were made at various depths Secchi disc measurements were taken.

5.2. THE ZOOPLANKTON FAUNA

Thirty species (listed in Appendix 5A) were identified in t summer plankton of Southern Indian Lake: 15 copepods and 15 clado Of these 30 species at least 25 can be qualified as true pelagic s and 5 as littoral ones.

The number of species found is extremely high and reflects very complex nature of this multibasin lake system. The list incl almost all species found in Laurentian Great Lakes (Patalas 1972) in particular very closely resembles that of Lake Winnipeg. It is mentioning that Senecella calanoides, a species usually occurring rather deeper lakes, was found in Southern Indian Lake.

Total numbers of crustaceans apparently varied in different of the lake (Figure 5.1). The lowest numbers, about 10 ind/l, were in the Churchill River and in the adjacent water masses (Opachuanau The main bodies of water have relatively uniform numbers within the range of 50-100 ind/l.

Numbers between 100-200 ind/l were encountered only in some protected bays or inshore waters isolated by islands from the main body (stations 23, 33, 34, 35, 48, 45, 50, 52). The highest number above 200 ind/l, were found in the well protected bays of the nort part in stations 54 and 55.

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Lake).

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5.3. HORIZONTAL DISTRIBUTION OF SPECIES

One can expect that within a well mixed water mass the
of planktonic animals will be relatively uniform. The deviat
this uniformity can be an indication of the existence of sepa
masses which either do not mix together or mix only to a limit
The analysis of the distribution of the particular species in
that quite a few species are restricted to certain areas whil
in others.

Figure 5.2 shows a generalized picture of the distinct
masses identified on the basis of the most frequent distribut
patterns. The whole lake can be divided into seven more or l
basins starting from the south-west end. However, within eac
basins a quite apparent west-east division can be made (marke
Figure 5.2 with letters W and E). The differences between we
eastern parts of the same basin (e.g. between 4W and 4E) are
greater than the differences between two or three consecutive
basins (e.g. 2E, 3E and 4E). This indicates that the eastern
the basins (OE, 1, 2E, 3E and 4E) represent the main flow rou
Churchill River waters (the area marked on the map with diffe
of cross), while the western parts remain to a greater degree
local influence of the north-western shore drainage. As an e
to how far these influences may extend, station 10, in spite
located centrally in the basin, bears more resemblance to th
western region described as 7 (Cleugh, Ayles and Baxter, 1974

the Churchill River waters represented by region 1. Most of the well isolated bays, particularly South Bay (5E, 6W) and the areas 5E and 5W are quite different from the main water mass indicating that little if any water exchange occurs between them.

A unique situation occurs in the area represented by stations 51, 56, 57. Four water masses of different origin, one from the Church River (4E), one the western drainage of the north basin (4W), one from the Waddi River (5E) and one from the Muskwesi River (5W) meet togethe in this area, creating an "ecotone" type of situation which, as a rul is more productive biologically than the individual components. A hig fish yield might be expected in such an area. This hypothesis is suppo by good commercial catches in this area (Weagle and Baxter, 1973).

The above-described general pattern of plankton distribution wit the emphasis placed on the west-east differences within each particula basin is in good agreement with the surface water temperature distribution (Figure 5.3) at the time of sampling. The eastern and south-eastern parts of the basins were, as a rule, one to two degrees (C.) warmer than the north-western ones. The apparent deviation from this pattern in South Bay can be explained by the shallower waters respondin more quickly to dropping air temperatures at the beginning of September than the deeper main basin.

5.4. PROBABLE EFFECTS OF DIVERSION

A prediction about the water mass distribution after t
diversion of the Churchill River waters through South Bay is
in Figure 5.4. Areas OW, OE, 7, 1, and 2E will demonstrate b
the same water mass distribution. South Bay will become an e
of area 2E. With the Churchill River contribution at Missi R
reduced to about 7% of its present level, the northern part
will be more similar to those waters presently flowing to are
5E, and in the central part of the lake - by waters now flowi
4W, 3W and 2W. Cleugh (1974) discusses some of the changes w
expected.

The ecotone situation created by the mixing of differe
masses will be reduced or will disappear completely. The nutr
will also be cut to about 15% of the present level (see Cleug
Based on these two changes one can predict that the biologica
after diversion will significantly drop in the central and no
of the lake. Any increase of Churchill River water flow thro
northern part of the lake will positively effect the producti
these parts.

APPENDIX 5A

LIST OF CRUSTACEAN SPECIES

Species		Average abundance indiv/liter
Copepoda		
Senecella calanoides	Juday	<0.01
Limnocalanus macrurus	Sars	0.04
Epischura lacustris	Forbes	0.88
Epischura nevadensis	Lilljeborg	0.50
Diaptomus ashlandi	Marsh	15.08
Diaptomus oregonensis	Lilljeborg	3.55
Diaptomus siciloides	Lilljeborg	2.61
Diaptomus sicilis	Forbes	0.54
Diaptomus minutus	Lilljeborg	2.39
Cyclops bicuspidatus thomasi	Forbes	28.51
Cyclops vernalis	Fischer	6.62
Mesocyclops edax	(Forbes)	0.24
Macrocyclops albidus	(Jurine)	<0.01
Tropocyclops prasinus mex.	Kieffer	<0.01
Eucyclops agilis	(Koch)	<0.01
Cladocera		
Daphnia retrocurva	Forbes	2.42
Daphnia galeata mendotae	Birge	0.87
Daphnia longiremis	Sars	1.82
Daphnia pulex	Leydig	<0.01
Ceriodaphnia quadrangula	(O.F. Müller)	<0.01
Simocephalus serrulatus	(Koch)	<0.01
Bosmina longirostris	(O.F. Müller)	2.85
Alona quadrangularis	(O.F. Müller)	<0.01
Chydorus sphaericus	(O.F. Müller)	6.76
Eurycercus lamellatus	(O.F. Müller)	<0.01
Graptoleberis testudinaria	(Fischer)	<0.01
Diaphanosoma leuchtenbergianum	Fischer	0.46
Sida crystallina	(O.F. Müller)	0.05
Leptodora kindtii	(Focke)	0.04
Holopedium gibberum	Zaddach	0.12
	TOTAL	76.36

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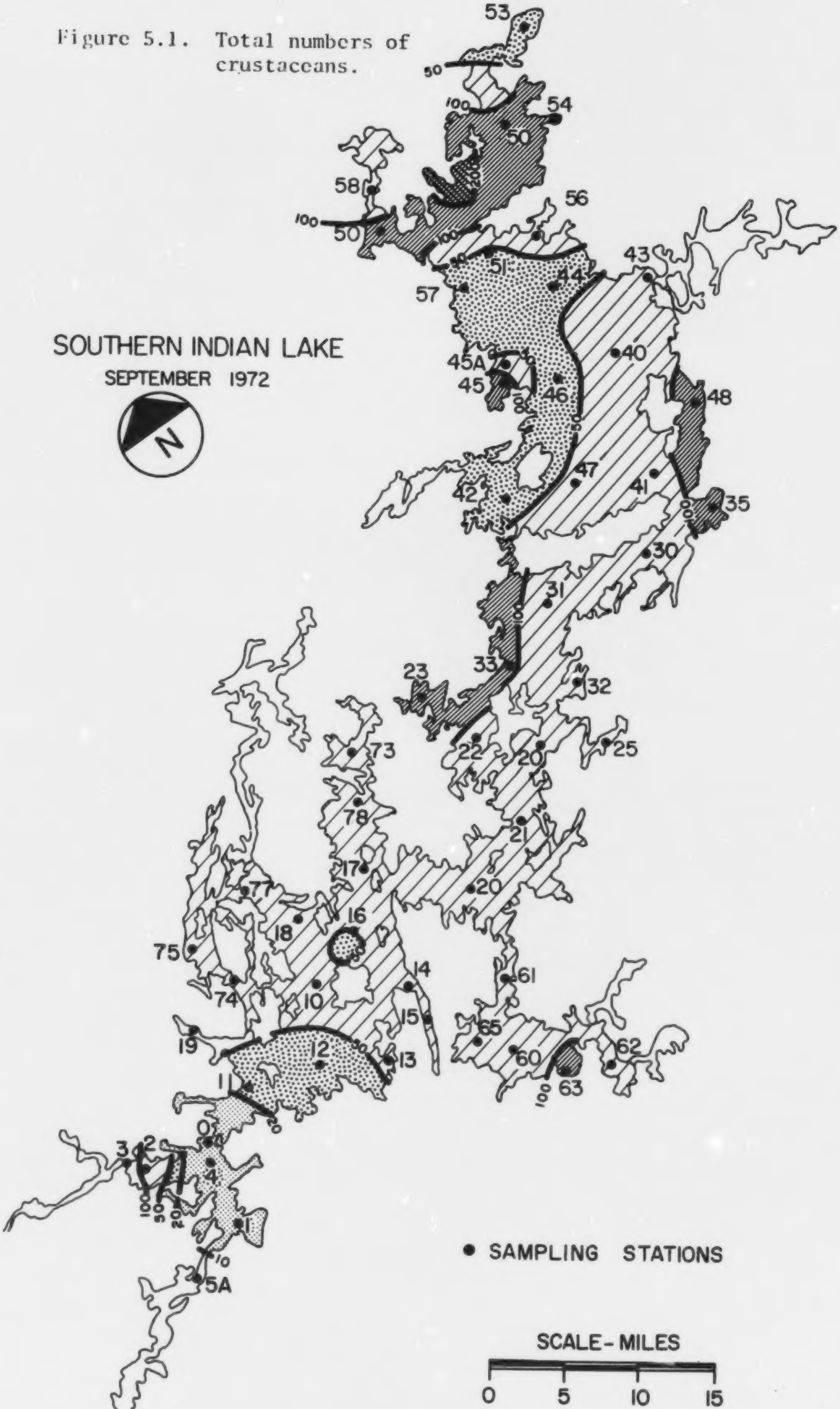
Cleugh, T.R. 1974. The hydrography of Southern Indian Lake: Present conditions and implications of hydroelectric development. MS prepared for Canada-Manitoba Lake Winnipeg, Churchill and Nelson Rivers Study. Environment Canada, Fisheries Service.

Cleugh, T.R., H. Ayles, and W. Baxter. 1974. The morphometry of Southern Indian Lake: Present conditions and implications of hydroelectric development. MS prepared for Canada-Manitoba Lake Winnipeg, Churchill and Nelson Rivers Study. Environment Canada, Fisheries Service.

Patalas, K. 1972. Crustacean plankton and the eutrophication of St. Lawrence Great Lakes. J. Fish. Res. Bd. Canada. 29:1451-1462.

Figure 5.1. Total numbers of crustaceans.


SOUTHERN INDIAN LAKE
SEPTEMBER 1972
N
SAMPLING STATIONS
SCALE-MILES
0
5
10
15
53
54
50
58
50
56
51
57
44
43
40
45A
45
46
48
42
47
41
35
30
31
33
23
32
22
20
25
73
78
21
17
20
77
18
16
75
74
10
14
15
61
65
19
12
13
60
62
63
11
0
3
2
4
1
5A
50
100
200
100
100
20
10
20
10
100
50
20
10

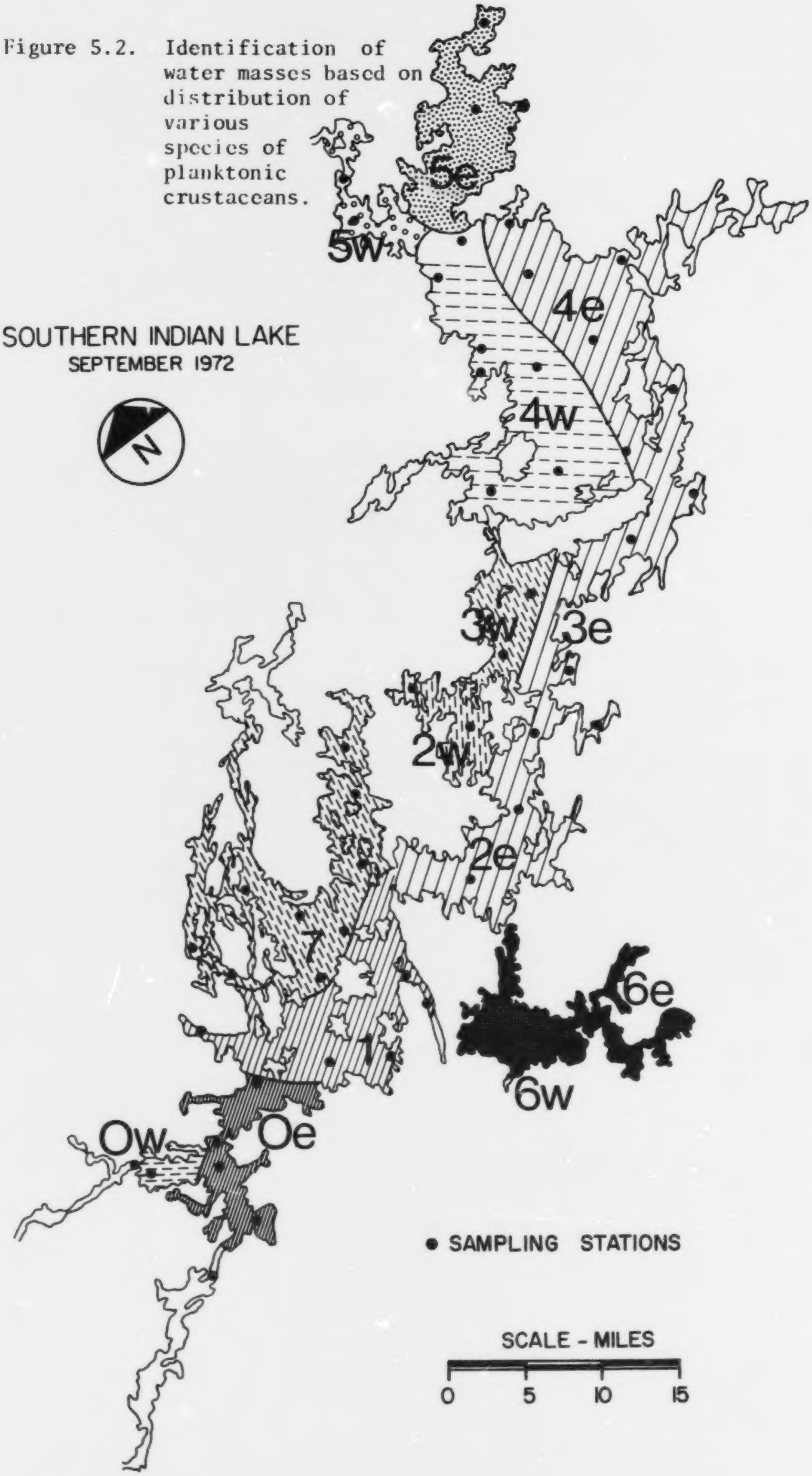


Figure 5.2. Identification of water masses based on distribution of various species of planktonic crustaceans.

SOUTHERN INDIAN LAKE
SEPTEMBER 1972
N
5e
5w
4e
4w
3w
3e
2w
2e
7
1
6e
6w
Ow
Oe
● SAMPLING STATIONS
SCALE - MILES
0
5
10
15

Figure 5.3. The distribution of water temperature at the surface (August 25-September 1, 1972).

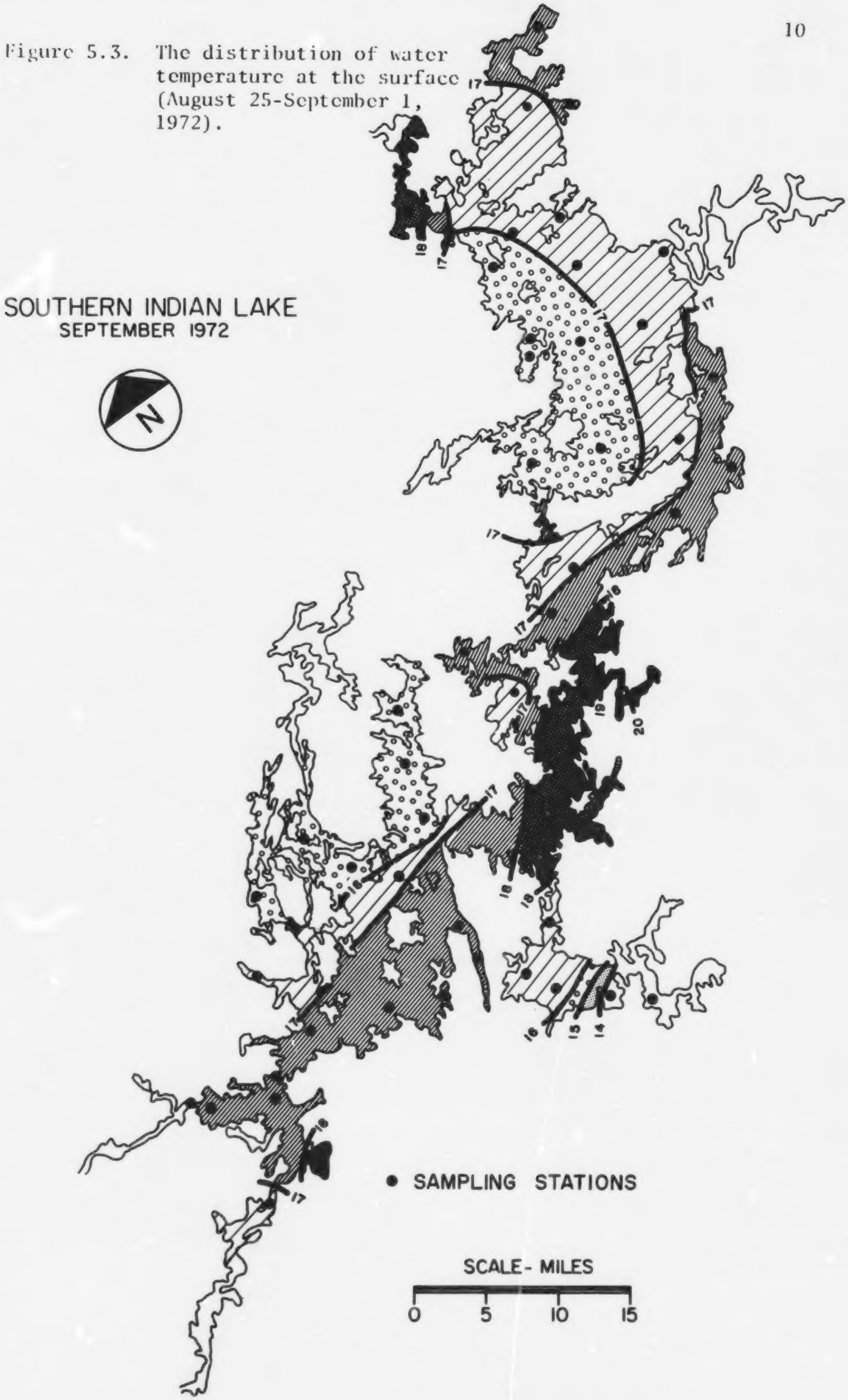
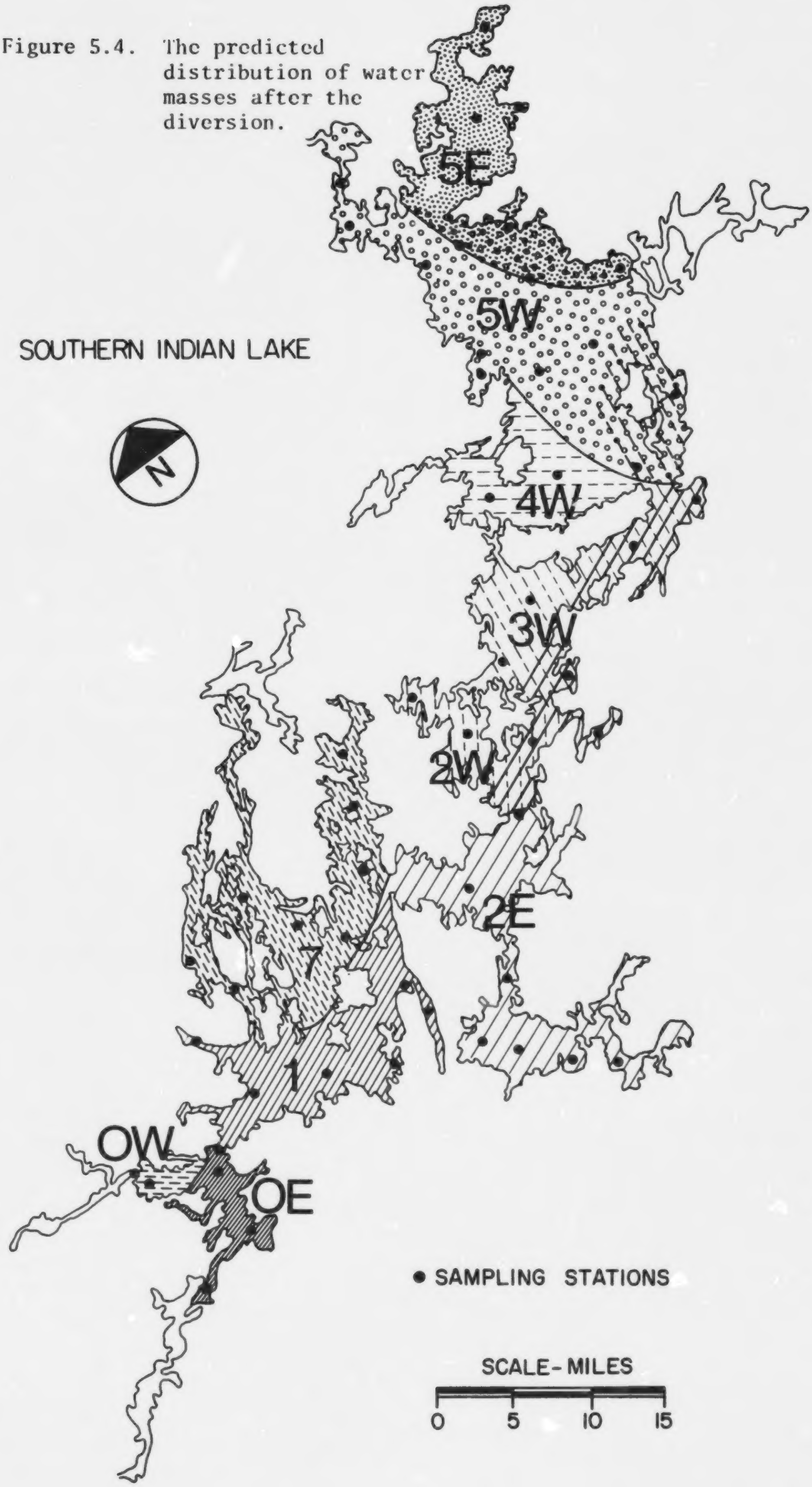

SOUTHERN INDIAN LAKE
SEPTEMBER 1972
N
17
18
17
17
17
18
17
17
19
20
17
18
18
18
16
15
14
17
18
17
● SAMPLING STATIONS
SCALE- MILES
0
5
10
15

Figure 5.4. The predicted distribution of water masses after the diversion.


SOUTHERN INDIAN LAKE
N
5E
5W
4W
3W
2W
2E
7
1
OW
OE
● SAMPLING STATIONS
SCALE-MILES
0
5
10
15

APPENDIX 5 - VOL. 1 - G.

ZOOBENTHOS SURVEY OF SOUTHERN INDIAN LAK

ZOOBENTHOS SURVEY OF SOUTHERN INDIAN LAKE

by

A. L. HAMILTON
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
February, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

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Figure 3. Average values of TDS, specific conductivity, Na, K, Mg, and C in areas of Southern Indian Lake expressed as a percentage of values found at station 9 (inlet to Southern Indian Lake) ....

Figure 4. Abundance of benthic invertebrates and *Pontoporeia* at sampling stations in Southern Indian Lake ..

Figure 5. Distribution of major taxonomic groups of zoobenthos in Southern Indian Lake ....

Figure 6. Distribution of chironomid subfamilies in Southern Indian Lake ....

6.0. SUMMARY

1) The average density of benthic macroinvertebrates in Sout Indian Lake was 3429 organisms/meter^2 (319 organisms/foot This is substantially greater than densities in most Shie lakes in the region.

2) The freshwater amphipod, Pontoporeia affinis, is the most abundant benthic organism in all regions excepting South

3) Chironomidae (midges) were the second most abundant group benthic invertebrates. Large Chironomus, an excellent wh food, were common in the region aroung Long Point and rar throughout the rest of the lake.

4) Sphaeriidae (finger nail clams), the third most abundant benthic invertebrates, were relatively uniformly distribu throughout the Southern Indian Lake.

5) Gastropoda (snails) were the most abundant group in South rare elsewhere.

6) On the average regions that are isolated or semi-isolated Churchill River had 29% fewer benthic invertebrates and 5 Pontoporeia than regions that are more directly influence Churchill River. South Bay had an unusually low density invertebrates.

7) Stations with water quality (TDS, Conductivity, Na, K, Mg similar to that at the inlet had substantially more benth invertebrates and Pontoporeia than stations with differen

quality.

8) The standing crop of zoobenthos in different regions of Southern Indian Lake follows a pattern similar to that of phytoplankton. The patterns of distribution of zooplankton and fish have similarities to that of the zoobenthos, but, comparisons are not as simple as the phytoplankton-zoobenthos patterns.

9) It is estimated that the overall benthic production in Southern Indian Lake is likely to be reduced by 15-30% following diversion. It is predicted that this decrease will result from a 25-50% reduction in the benthic productivity in the area north of South Bay. The southwestern part of the lake will likely be relatively unaffected by diversion and conditions in South Bay should improve.

6.1. INTRODUCTION

The term, zoobenthos, refers to the invertebrates that live in or upon the bottom sediments in aquatic habitats. Characteristically this benthic community plays an important role in the metabolism of an aquatic ecosystem and in Southern Indian Lake this link in the food chain or food web is of critical importance to bottom-feeding species such as whitefish. In addition the young of yellow walleye and northern pike, two carnivorous species often feed extensively on zoobenthos. The quantity and quality of zoobenthos are also good indicators of the general productivity of a waterbody. Consequently, differences in abundance and composition of the zoobenthos in different parts of a lake can often provide useful information on the regional factors influencing general productivity as well as provide a measure of the capacity of an area to support stocks of bottom-feeding fishes.

The primary objectives of the zoobenthos survey on Southern Indian Lake were

1) Determine the abundance and composition of zoobenthos in different regions of Southern Indian Lake and to compare the results to those found in other lakes in the area.

2) Relate abundance and composition of zoobenthos in different parts of the lake to physical and chemical factors. One particularly important aspect is to assess the impact of the Churchill river on zoobenthos of Southern Indian Lake.

3) Relate abundance and distribution of zoobenthos in Southern

Indian Lake to that of other biological components of the ecosystem.

4) Predict the likely impact of diversion of the Churchill River at South Bay on the abundance and composition of zoobenthos in Southern Indian Lake.

I am particularly pleased to acknowledge the assistance of Mr. G. P. McRae,who spent endless hours sorting invertebrates from sieve residues, compiling data sheets and carrying out a variety of analytical procedures on the zoobenthos data from Southern Indian Lake. The assistance of Mr. Tom Cleugh, Mr. Les Sherwood and Mr. Les Seminiuk, who took most of the collections is also appreciated.

6.2. METHODS

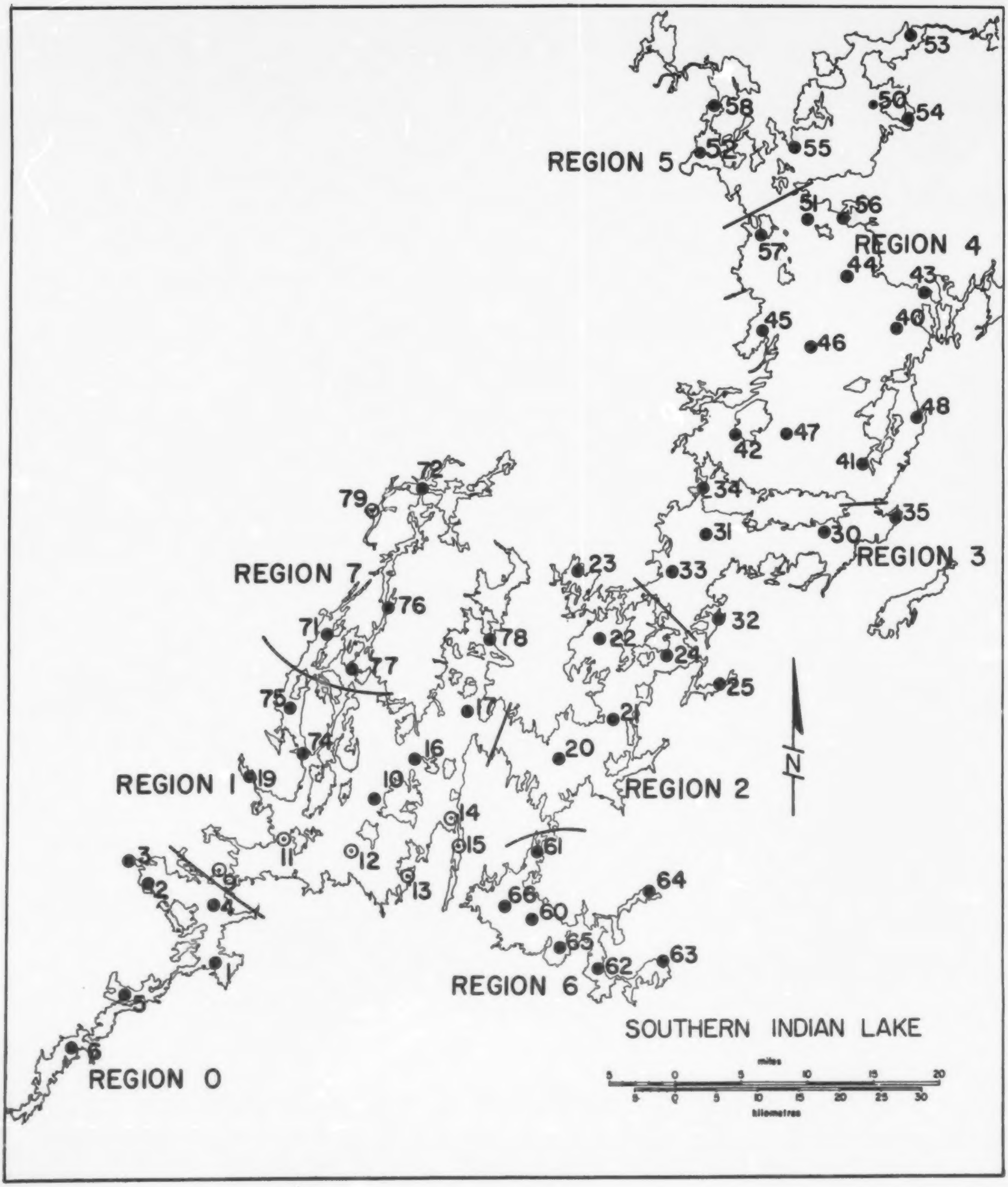
6.2.1 Collection and identification of material:

The zoobenthos survey on Southern Indian Lake, Opachuanau Lake and the Churchill River immediately above Opachuanau Lake was conducted between July 2, 1972 and July 16, 1972 excepting for three stations (10, 16 and 17) which were sampled on July 30, 1972. A total of 101 samples at 53 stations (Figure 1) were collected using a 15x15x23 cm tall Ekman grab. Sediments were sieved in the field using a Nitex nylon mesh net (apertures 400μ square) and the sieve residues were preserved in approximately 10% formalin. In the laboratory the samples were rinsed to remove most of the formalin and the invertebrates sorted from the residue with the aid of a stereomicroscope. All organisms were then preserved in 70% ethanol.

Most organisms were identified using a stereomicroscope while the more difficult specimens of some of the insect larvae were mounted on glass slides and examined under a compound microscope. Copepoda, Cladocera and Ostracoda were preserved but not enumerated because they were too small to have been sampled quantitatively.

6.2.2 Establishment of areas for regional analysis:

To facilitate analysis the area sampled was broken down into a number of regions. The original numbering system (Figure 1) was an initial attempt at dividing the lake into regions. This system was developed by simply looking at a map of the lake and estimating the extent to which Churchill River water would be mixed with water from the more isolated parts of the lake.


53
58
50
54
REGION 5
52
55
51
56
57
REGION 4
44
43
45
46
40
48
42
47
41
72
34
79
35
31
30
REGION 3
REGION 7
23
33
76
32
71
78
22
24
77
25
75
17
21
74
16
20
REGION 1
19
10
REGION 2
N
14
11
15
61
3
12
9
2
13
64
4
66
60
1
65
63
62
REGION 6
5
SOUTHERN INDIAN LAKE
6
REGION 0
miles
5
0
5
10
15
20
5
0
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10
15
20
25
30
kilometres

Figure 1. Locations of zoobenthos sampling stations in Southern Indian Lake.

This initial estimate was then improved by developing a simple index of the chemical impact of the Churchill River on water samples collected throughout the lake. Station 9 at the inlet of Southern Indian Lake was sampled 7 times between June 1, 1972, and October 4, 1972 (Cleugh 1973). Six parameters (total dissolved solids, specific conductivity, sodium, potassium, magnesium and calcium) were selected as "tracers" because they are all relatively conservative parameters that are largely unaffected by biological activity. Since the samples at station 9 were taken at essentially equal intervals the standard value of each of these parameters (P_s) was then considered to be simply the average of the seven determinations. The parameter values at each of the zoobenthos stations (P_x) was usually the average of two analyses, one taken in early July (zoobenthos cruise) and the other in late August (zooplankton cruise). In a few instances only one analysis was available. The percent difference between the inlet water and the water at each station was then calculated as follows:

$$\text{Percent difference} = \frac{\Sigma \; \frac{d_x}{P_s} \times 100}{n}$$

where $d_x = P_s - P_x$ always expressed with a positive sign

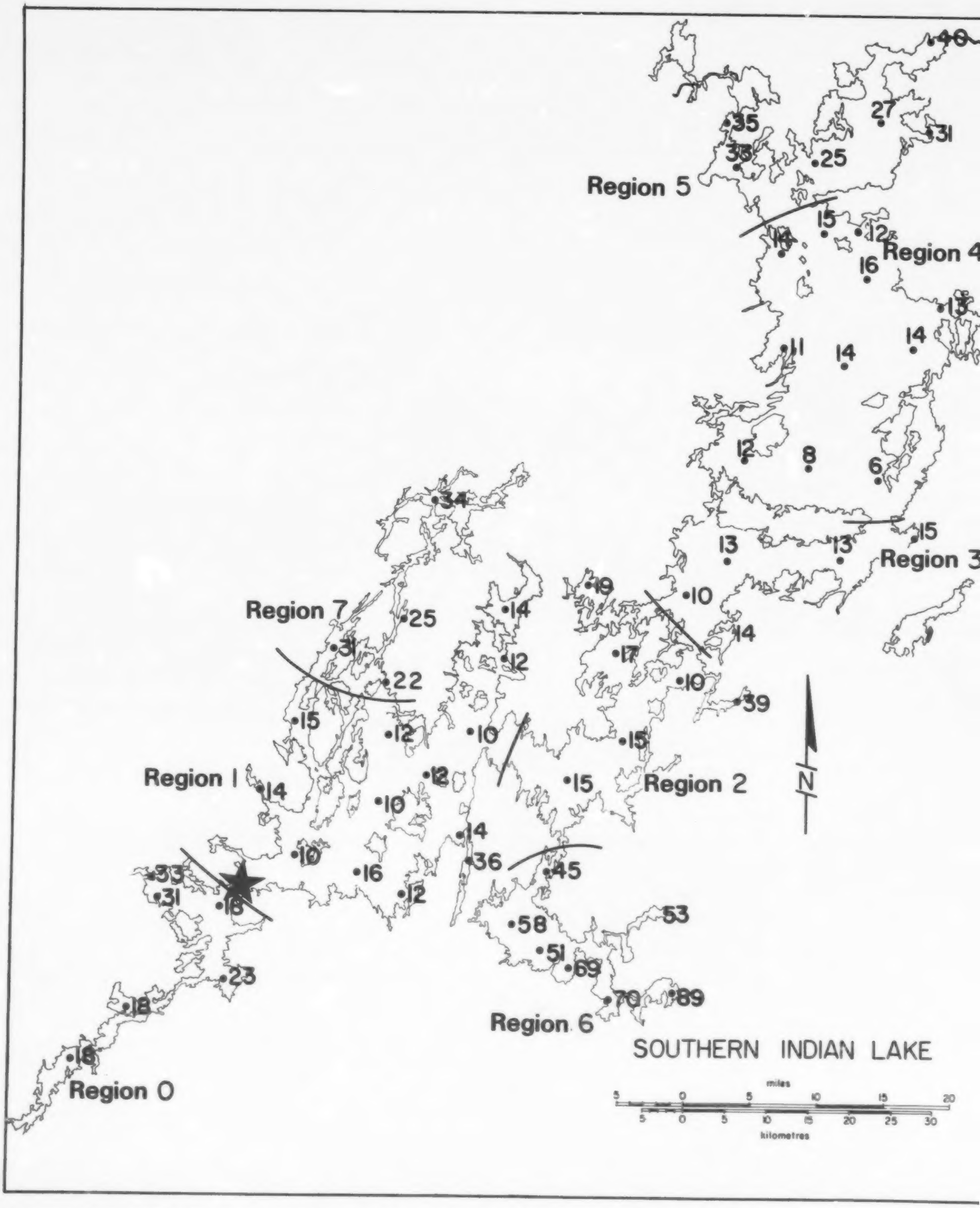
and $n = 6$, the number of parameters

A rough measure of seasonal and analytical variation and/or errors was estimated by calculating the percent difference between individual samples taken at station 9 and the average value of the other six samples. Six of the values were between 7 and 15 while the value for the first sample on

June 1 was 24. With this level of variation it was estimated that values at individual stations would have to be at least 20 before one could assume that the water was probably significantly different from Churchill River water. After this analysis it became clear that the Churchill River has a major influence on a significantly larger part of the lake than initiall expected. As a consequence the boundaries of region 1 were extended to inclu stations 74, 75 and 78 and the boundaries of region 4 were extended to includ stations 51, 56 and 57 (Figures 2 and 3). The regional divisions selected for this analysis are as follows:

Region 0	Churchill River and Opachuanau Lake. Much of this area is more river than lake. The water chemistry at two stations, 2 and 3, is markedly influenced by the Barrington River (Figures 2 and 3).
Region 1	Southwestern Southern Indian Lake. This part of the lake is dotted with islands and is apparently greatly influenced by the Churchill River.
Region 2	Southern Indian Lake immediately north of the South Indian settlement. Relatively narrow channel with many islands.
Region 3	Southern Indian Lake immediately south of Long Point. Relatively narrow channel with many islands. Water chemistry at all stations similar to that at Opachuanau Rapids.
Region 4	Southern Indian Lake in large relatively open part of the lake north of Long Point. Water chemistry at all stations similar to that at Opachuanau Rapids.
Region 4	North end of Southern Indian Lake. Water chemistry indicates that all stations are relatively isolated from the main flow of the Churchill River.

Region 6	South Bay. Apparently very isolated from the main flow of t Churchill River.
Region 7	Northwestern part of Southern Indian Lake. Narrow channels appear to be isolated from the major flow of the Churchill R


40
35
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31
25
Region 5
15
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14
Region 4
16
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13
Region 3
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10
Region 7
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Region 1
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15
Region 2
N
10
14
10
36
45
16
33
12
31
16
53
58
51
69
23
70
89
18
Region 6
SOUTHERN INDIAN LAKE
18
Region 0
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

Figure 2. Distribution of chemical percent difference values in Southern Indian Lake
Values of TDS, specific conductivity, Na, K, Mg and Ca at Station 9 (inlet
to Southern Indian Lake) were taken as the standard.

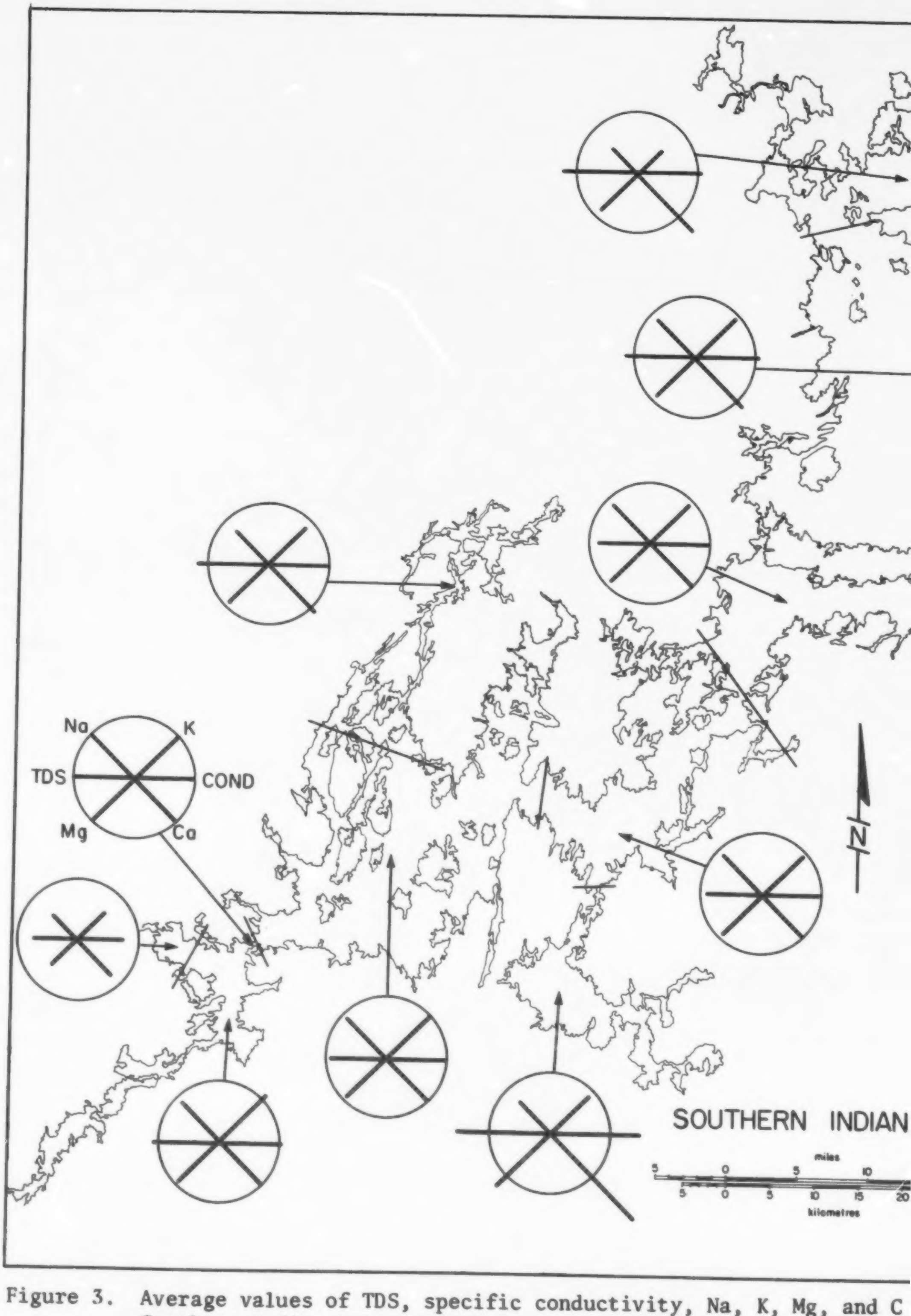
Na
K
TDS
COND
Mg
Ca
N
SOUTHERN INDIAN
miles
5
0
5
10
5
0
5
10
15
20
kilometres

Figure 3. Average values of TDS, specific conductivity, Na, K, Mg, and C
Southern Indian Lake expressed as a percentage of values found
(inlet to Southern Indian Lake).

reas of
tation 9

6.3. ABUNDANCE AND DISTRIBUTION OF ZOOBENTHOS

6.3.1 Comparative evaluation of Southern Indian Lake zoobenthos:

The average density of benthic invertebrates in samples from Sc Indian Lake was 3,429 per square meter (319 per square foot). This de is two to tens times higher than that reported by Rawson (1960a) for c large lakes such as Cree, Wollaston and Reindeer located in the same g region. It is also higher than that reported for most of the Churchil in Saskatchewan (Rawson 1957; Rawson 1960b, and Koshinsky 1971). Hami (1971) reported that 15 small lakes in the Canadian Shield near Kenora an average of 1,552 benthic organisms/meter^2 with a range of values fr to 3,556 organisms/meter^2.

Rawson and Koshinsky used a larger mesh for sieving their sampl however, it seems very unlikely that mesh size alone could explain the comparatively high values for samples from Southern Indian Lake. Samp techniques used on the small lakes near Kenora were identical to those on this study. It should be noted that when other variables are simil lakes are generally much less productive on a per-unit area basis than lakes and lakes at high latitudes are usually significantly less produc than lakes in more moderate climates.

It is clear that the zoobenthos of Southern Indian Lake is considerably richer than would ordinarily be expected in a lake of this size at this latitude. The physical and chemical influence of the Chur River has almost certainly had a very positive effect on the productior zoobenthos in Southern Indian Lake. The results from Southern Indian I

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did not come as a surprise since other studies in Saskatchewa
Rawson 1960, and Koshinsky 1971) have also demonstrated that
in Churchill River lakes is almost always considerably riche
zoobenthos in nearby Shield lakes.

6.3.2 Relationship to physical and chemical parameters:

In the following analysis of zoobenthos communities t
River and Opachuanau Lake (Region 0) are excluded because compa
is essentially a river region with seven lake regions would comp
analysis, especially since the sampling gear utilized was no
quantitatively sample river substrates. Principle relations
follows:

1) The freshwater shrimp (Pontoporeia affinis), a v
whitefish food, was the most abundant benthic or
regions of Southern Indian Lake excepting region 6 (
It is especially abundant in regions along the mai
Churchill River (Figure 4, Table 1). On a lake-
Pontoporeia represented 45% of the total standin
benthic macroinvertebrates.

2) The densities of benthic invertebrates and Ponto
1, 2, 3, and 4, which for the most part appear t
markedly influenced by the flow of the Churchill
were on the average considerably higher than den
5, 6, and 7 which are more isolated than the flo
River (Table 1). In percentage terms the regions
Churchill River had 29% fewer organisms and 52%
than regions that were more directly influenced by

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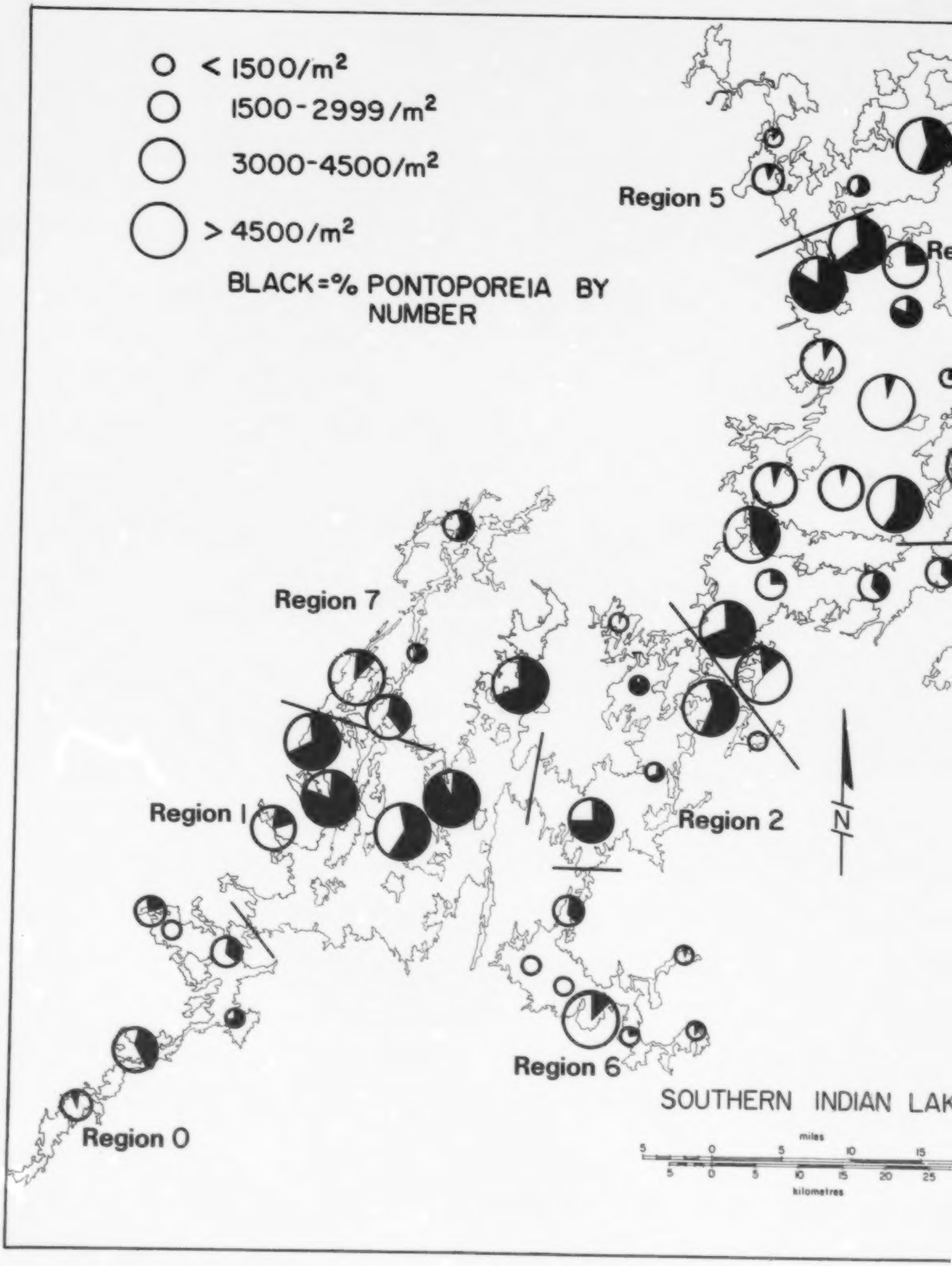

< 1500/m²
1500-2999/m²
3000-4500/m²
> 4500/m²
BLACK=% PONTOPOREIA BY NUMBER
Region 5
Re
Region 7
Region 1
Region 2
Region 6
Region 0
N
SOUTHERN INDIAN LAK
miles
5 0 5 10 15
5 0 5 10 15 20 25
kilometres

Figure 4. Abundance of benthic invertebrates and *Pontoporeia* at sampling stat
in Southern Indian Lake.

gion 4
Region 3
E
20
30

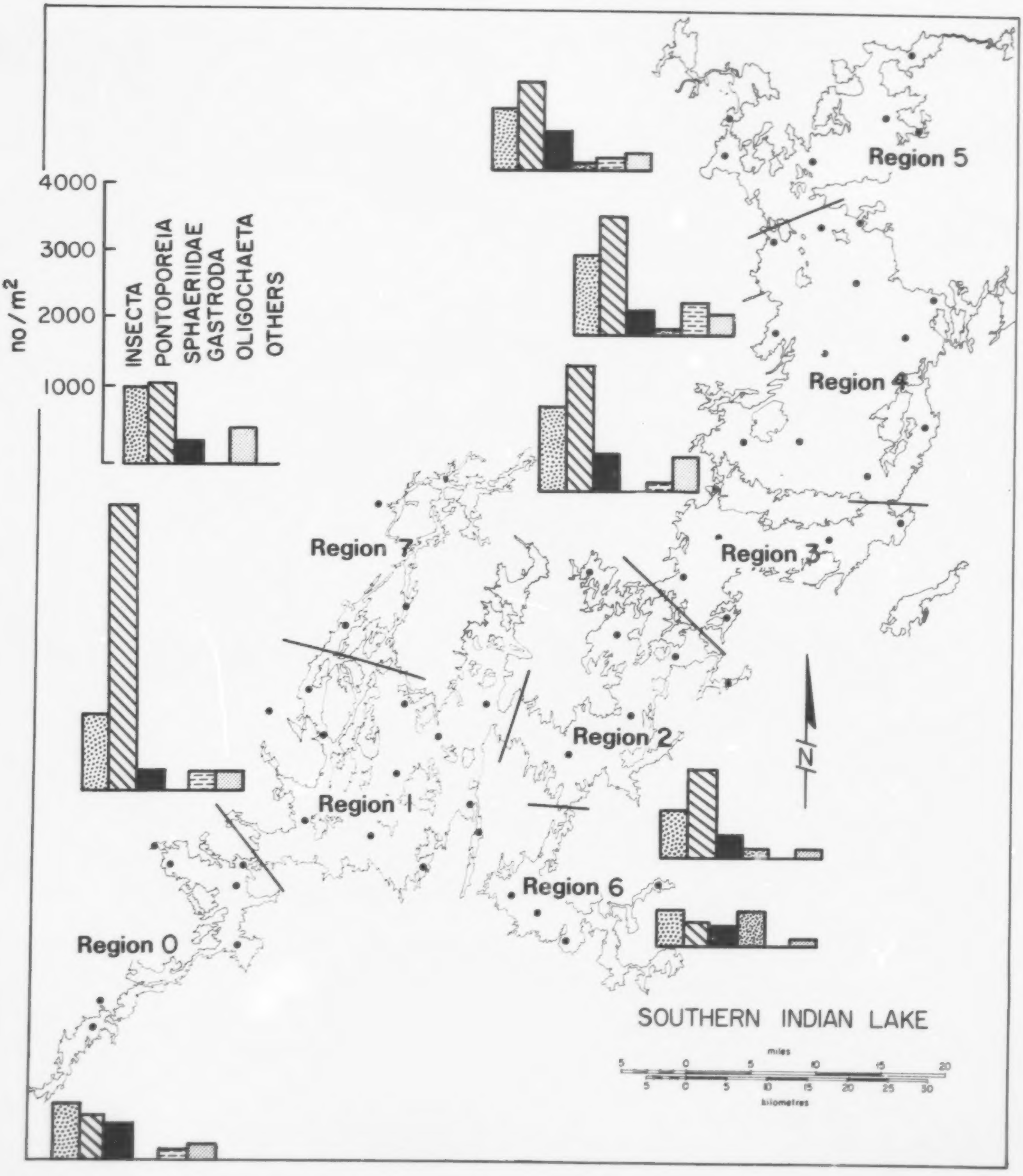
ons

Churchill.

3) When compared on a station-by-station basis it is a the zoobenthos at stations where the water is appar almost entirely from the Churchill River are substa than stations more isolated from the Churchill 2). This is true in both the shallow (0-7.5 meters (7.6-15 meters) depths of the lake. A co the deeper water (>15 meters) was not possible beca stations were located in the medium (21-40) or high percent difference areas.

4) Midge larvae (Chironomidae) accounted for 25% of be organisms in this survey and were the second most n in the lake (Figure 4, Appendix Table 1). The Tany largely carnivorous taxon, were quite uniformly dis were the most abundant chironomid group in Regions 2 Tanytarsini were the most numerous group in Regions 1 while larger Chironomini were the most numerous gro 3 and 4 (Figure 5). The genus Chironomus, an excel fish food, was relatively common in Regions 3 and 4 (abundance = 472 individuals/m^2) and relatively rare the rest of the lake (36 individuals/m^2). A total Chironomidae were identified from the Southern Ind samples (Appendix Table 2).

5) Finger nail clams (Sphaeriidae) were the third most taxonomic group of benthic invertebrates (11% of to group was relatively uniformly distributed througho Southern Indian Lake and there was no clear indicat


4000
3000
2000
1000
no/m^2
INSECTA
PONTOPOREIA
SPHAERIIDAE
GASTRODA
OLIGOCHAETA
OTHERS
Region 5
Region 4
Region 3
Region 2
Region 7
Region 1
Region 6
Region 0
N
SOUTHERN INDIAN LAKE
miles
5
0
5
10
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5
0
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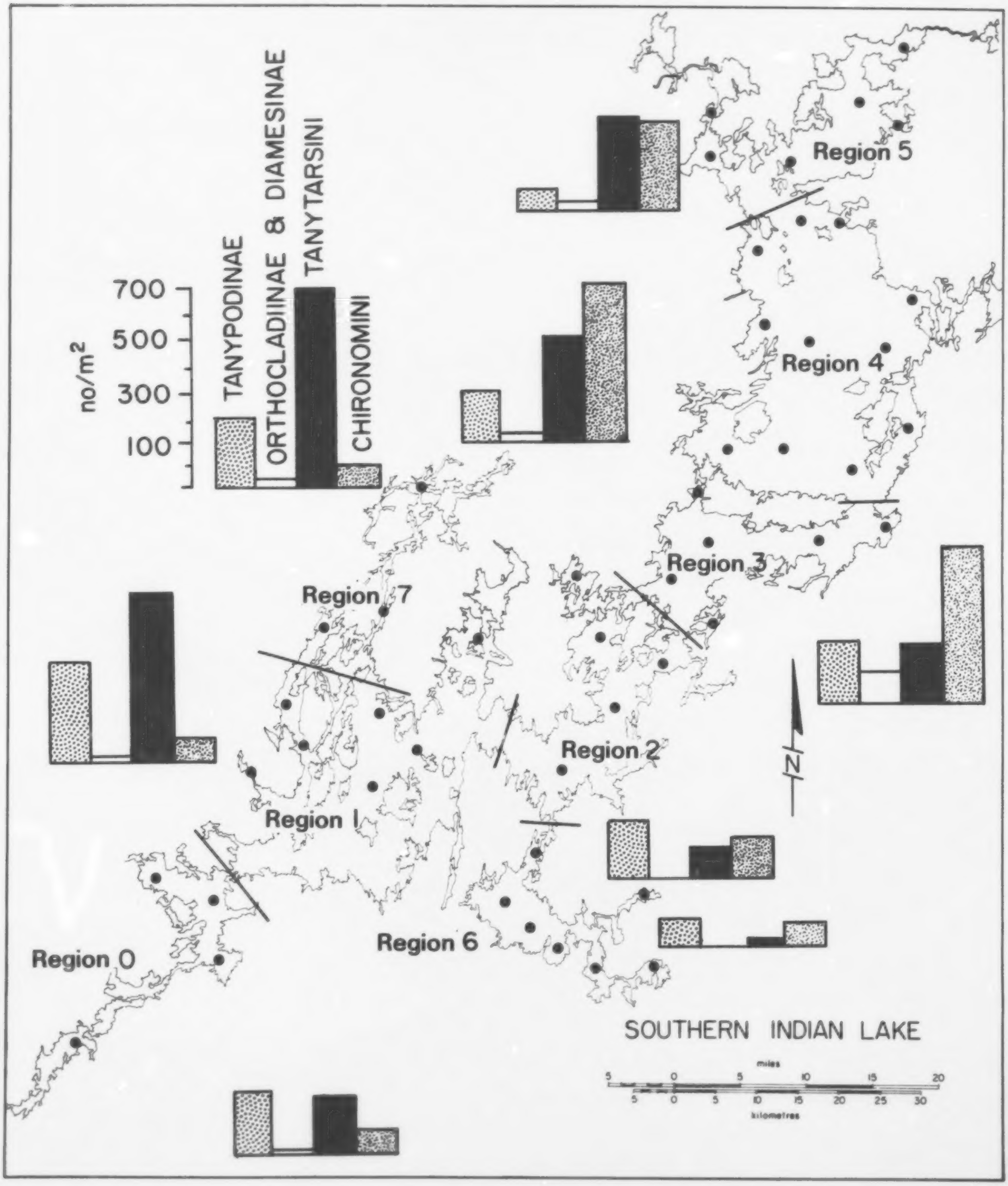
20
25
30
kilometres

Figure 5. Distribution of major taxonomic groups of zoobenthos in Southern Indian Lake.


no/m^2
700
500
300
100
TANYPODINAE
ORTHOCLADIINAE & DIAMESINAE
TANYTARSINI
CHIRONOMINI
Region 0
Region 1
Region 2
Region 3
Region 4
Region 5
Region 6
Region 7
N
SOUTHERN INDIAN LAKE
miles
5
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10
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20
25
30

Figure 6. Distribution of chironomid subfamilies in Southern Indian Lake.

the flow of the Churchill River had a significant influence on the abundance of this group. Specific and generic determinations were not made but it is expected that the species composition would differ between different regions.

6) Snails (Gastropoda) were the most abundant group of organisms in Region 6 and were rare in all other regions. Station 65 was much richer than other stations sampled in South Bay (Figure 4, Appendix Table 1). The samples from this station indicated a density of over 8,000 organisms/m^2 including over 3,700 gastropods/m^2. More than twice as many gastropods were collected at this station than at all the remaining stations in Southern Indian Lake combined.

7) There is considerable variation between samples - even from samples within the same region. This is typical of benthos surveys and is related to numerous variables including depth, substrate type, dredge effectiveness and sorting efficiency. Estimated densities are undoubtedly low since no sampler is 100% effective under all conditions.

6.3.3 Relationship to other biological parameters:

Each of the biological communities that were examined in the Southern Indian Lake study provide useful information on the productivity of the system.

Phytoplankton and periphyton have a very short life cycle that can be measured in days and these groups can respond very quickly to changes in water quality. Phytoplankton are carried passively by water currents while periphyton will attach to any suitable substrate.

Table 1. Densities of benthic invertebrates and Pontoporeia in the 7 regions of Southern Indian Lake.

	Regions	Number of Stations	Organisms/m^2	Pontoporeia/m^2
Regions directly influenced by Churchill River water	1	7	6441	3798
	2	6	2311	1278
	3	6	4400	1837
	4	12	4161	1644
	Average		4364	2097
Regions isolated or semi-isolated from Churchill River water	5	6	3364	1381
	6	7	1930	359
	7	4	3250	1110
	Average		3113	1015

Table 2. Relationship between the percent difference, depth and the densities of benthic invertebrates and *Pontoporeia* in Southern Indian Lake. Percent difference (see Methods section) is a chemical measure of the influence of the Churchill River. Values less than 20 indicate that on average the total dissolved solids, specific conductivity sodium, potassium, magnesium and calcium were rather similar to values obtained at station 9 (Opachuanau Rapids). Number of stations indicated in parenthesis.

Percent Difference	Depth 0-7.5 meters		Depth 7.6-15.0 meters		Depth >15.0 meters	
	Totals	*Pontoporeia*	Totals	*Pontoporeia*	Totals	*Pontoporeia*
0-20	3975	1128	4867	2890	4302	2091
	(8)		(10)		(13)	
21-40	1891	533	4350	1839	-	
	(9)		(5)			
>40	2450	411	1237	289	-	
	(4)		(3)			

Zooplankton crustaceans are also carried more or less passively by water currents; however, they have a life cycle several times longer than phytoplankton and consequently their response time to altered water quality is much slower. In addition most plankton crustaceans are not well adapted to living in rivers and consequently their greatest abundance in Southern Indian Lake seems to be more associated with the degree of protection from currents rather than with water quality.

The zoobenthos fauna can be regarded as an integrater of annual conditions since most benthic invertebrates have a one-year life cycle and individual organisms remain on or in the lake sediments for most or all their life span. Most benthic invertebrates feed on organic detritus and/or other invertebrates and consequently distribution and abundance in lakes is usually related to biological production in the water column.

The fish fauna represent an even longer integrater of conditions in a lake since the life cycle for most species is of several years' duration. Fish are also capable of migrating long distances and consequently it is quite likely that an individual fish specimen will have spent different parts of his life in different regions of the lake.

As anticipated the standing crop of phytoplankton and periphyton to a large extent paralleled the distribution of zoobenthos (Hecky, Harper and Kling, 1973). In both situations Region 6 (South Bay) had the lowest standing crop while on the average the areas directly influenced by the Churchill River (Regions 1, 2, 3 and 4) had a higher standing crop than Region 5 at the North end of the lake.

Zooplankton standing crop and the standing crop of zoobenthos was generally not well correlated. (Patalas, 1973). The degree of protection from strong currents seems to have been the overriding factor for zooplankton whereas productivity in the overlying water column appears to have been more important to the zoobenthos community. In sheltered areas the relationship appears to be much more direct. For example, both zooplankton and zoobenthos were significantly more abundant at station 65 than at any other station in South Bay.

Whitefish, a bottom feeder, were relatively rare in South Bay (Ayles 1973). This is consistent with the low standing crop of benthic invertebrates in the area. Similarly very few whitefish were collected in Region 7. This area had a moderate population of benthic invertebrates but Pontoporeia, the major whitefish food, was only about half as abundant in Region 7 as in the areas directly influenced by the Churchill River. Whitefish were relatively more common in Region 5 than would have been predicted from benthos data. The ranking of food organisms in whitefish stomachs was 1 - Pontoporeia, 2 - Sphaeriidae, 3 - Gastropoda, 4 - Chironomida and 5 - Ephemeroptera. These same groups ranked 1, 3, 6, 2 and 7 in the zoobenthos samples. The relatively high proportion of Sphaeriidae, Gastropoda and Ephemeroptera may indicate that the whitefish are selectively feeding on these relatively large organisms. On the other hand part of the reason for this apparent selection may result because the large size of these organisms probably ensures that they will remain in stomachs for a longer period than more easily digested Chironomidae or Oligochaeta.

6.4. IMPLICATIONS OF PROPOSED HYDRO-ELECTRIC DEVELOPMENTS

6.4.1 Rationale and basic assumptions:

Southern Indian Lake will be no ordinary hydro-electric reservoir and consequently the usual arguments concerning the impact of hydro-electric reservoirs on biological productivity are not as applicable as one might expect. In a more typical situation when a lake is impounded for hydro-electric purposes the level of the lake is raised but the outl of the lake remains at the same location and flow patterns are not drastically changed. In addition most hydro-electric reservoirs are subject to very severe winter drawdown. When these situations prevail it is usually safe to predict that 1) input of nutrients from flooded land will produce an initial increase in benthic productivity; 2) winter drawdown patterns will drastically reduce littoral zoobenthos; and 3) benthic production in the reservoir will eventually stabilize at a level somewhat below pre-impoundment levels. It would be unwise to accept suc general predictions without first taking the unique features of the Southern Indian Lake development into account.

The principle factors considered to be of prime importance in the prediction of benthic productivity in Southern Indian Lake are:

1) The over-riding importance of the Churchill River as a source of nutrients for Southern Indian Lake. Diversion of the Churchill River at South Bay will eventually reduce the amoun of nutrients (fertilizer) entering Regions 3, 4 and the eastern part of 2 to approximately 1/10 of the present rate.

2) The role of the Churchill River in physically mixing the waters of Southern Indian Lake and thereby helping to prevent thermal stratification. The relative importance of river turbulence as opposed to wind action is not well understood; however, reduced flow in Areas 3 and 4 could have some effect on stratification. Present summer conditions where the lake is isothermal with bottom temperatures of 15°C or more foster high benthic productivity.

3) Winter drawdown patterns following diversion will probably not be significantly different from the present situation. Certainly there is no reason to suspect that winter drawdown will have a major impact on littoral zoobenthos.

4) Shoreline erosion and stabilization rates are essentially unknown factors both in terms of initial and long-term impact. Exposure of Aggasiz sediments on the new shoreline to wave action will result in the release of substantial quantities os nutrients; however, any positive effects of these nutrients will almost certainly be cancelled because of the increased turbidity resulting from erosion of these permafrost soils.

These four factors are all unlike those found in most reservoirs that have been studied intensively. Changes in the chemical and physical impact of the Churchill River will undoubtedly be important whereas winter drawdown will probably have an insignificant impact. Shoreline erosion and stabilization are potentially very important factors that, if anything, are likely to have an overall negative impact on the zoobenthos community.

6.4.2 Predictions:

The following predictions are based on the tenuous assumption that shoreline erosion and stabilization will not significantly affect wat quality in Southern Indian Lake.

1) Regions 0, 1, 5, 7 and the west half of Region 2 can be expect to remain essentially as productive for zoobenthos as they at present. Similarly the relative importance of Pontopor can be expected to remain unchanged.

2) Region 3, 4 and the east half of Region 2 will become signific less productive and will probably stabilize at a level 25% 50% lower than at present. Pontoporeia will probably decr proportionately and large Chironomus will be largely repla by smaller Tanytarsini.

3) Region 6 will become more productive and benthic productivit is likely to be **similar** to present levels in Regions 1, 2, 3 Pontoporeia will show a marked increase although it is doubtful that it will become the dominant group in the So Bay benthos community.

4) Overall benthic production in Southern Indian Lake is like to be reduced from 15-30% with the bulk of this reduction occurring in prime fishing areas (Regions 3 and 4).

If shoreline erosion and shoreline stabilization develop into t kind of problem that some predict then the increased turbidity could h a serious deleterious effect on benthic productivity as well as all ot aspects of biological productivity. While recognizing this possibilit I am presently not prepared to predict that the effects will be as dis as some information indicates. This is one aspect that should be stud carefully after Southern Indian Lake has been impounded.

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6.6. APPENDICES

APPENDIX TABLE 1. Distribution of benthic invertebrates in Southern Indian Lake. Substrate code: 1 - brown mud; 2 - grey clay; 3 - sand; 4 - gravel; 5 - rock; 6 - nodules.

STATION	SAMPLES	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROP-TERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLAN-EOUS	TOTAL
01	2	7.5	2-6	88	133	-	867	111	-	22	-	-	-	1221
02	2	5.0	2	443	44	-	-	266	-	67	-	220	-	1040
03	2	4.5	1	177	200	-	399	932	44	-	-	44	-	1796
04	2	9.7	2	666	67	-	1110	533	-	466	-	89	-	2931
05	2	8.0	5	887	44	22	1265	666	22	22	-	111	22	3061
06	2	9.0	5	1108	178	-	22	422	-	22	-	200	-	1952
10	2	17	-	466	-	-	3574	222	-	1110	-	400	-	5772
16	2	21	1	355	-	-	4707	-	-	-	-	-	-	5062
19	2	-	1	1352	266	-	822	1088	-	89	-	577	89	4283
20	2	19.7	1-6	510	-	-	2997	422	-	-	22	44	-	3995
21	1	11.0	1-4	222	-	-	621	44	-	-	-	44	-	931
22	2	23.7	1-4	88	-	-	1265	-	-	-	-	44	-	1397
23	2	3.2	1-2	687	266	-	44	200	44	-	-	-	-	1241
24	2	18.5	1-6	1043	22	-	2730	710	-	-	-	89	-	4594
25	2	2.5	1	554	222	-	-	22	200	44	-	200	-	1242
30	2	19.6	1-3	399	-	-	866	688	22	-	-	67	-	2042
31	2	15.5	1	444	22	-	533	777	-	220	-	244	-	2240
32	1	14.5	1-2	3553	-	-	755	555	-	200	-	133	-	5196
33	2	13.6	1-2	621	22	-	4617	244	-	488	22	577	-	6591
34	2	3.5	2	1420	67	-	3685	710	-	220	22	2331	-	8455
35	2	3.7	2	620	111	-	555	-	-	44	-	22	-	1352
40	2	21.8	1-4	88	-	-	67	67	-	44	-	-	-	266
41	2	15.3	1-2	1821	-	-	5283	866	22	710	44	266	-	9012
42	2	18.1	1-2	1244	-	-	222	244	-	1288	22	178	-	3198
43	1	12.4	3-6	310	-	-	245	67	-	-	-	44	-	666
44	2	15.9	4	155	-	-	1354	133	22	67	-	-	-	1731
45	2	6.0	1	1531	-	-	355	755	-	89	-	111	-	2841
46	2	?	2	2997	-	-	444	44	-	1643	-	244	-	5372
47	2	18.4	1-2	3129	-	-	66	244	44	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

				376	-	-	1953	1132	22	133	-	1199	-	4815
50	2	10.7	1	711	-	-	4751	2220	-	422	-	178	-	8283

51	2	16.6	1-2	444	-	-	4706	200	-	422	-	1421	-	7193
52	2	4.4	1	443	22	44	178	355	-	533	-	67	-	1642
53	2	2.6	2	355	-	-	242	311	44	-	-	666	-	1618
54	2	3.7	2-3	3039	-	34	2620	266	133	-	-	311	-	6680
55	2	7.0	1-3	221	-	-	400	44	22	-	-	44	-	731
56	2	5.4	2	1863	-	-	865	444	222	-	-	-	-	3394
57	2	11.5	1-2	310	-	-	3774	-	-	200	-	333	-	4617
58	2	1.7	2	44	200	-	89	44	67	111	-	-	-	555
60	2	8.1	1-2	22	-	-	-	111	67	22	-	133	22	377
61	2	8.3	1	309	289	-	866	178	133	-	-	266	-	2041
62	2	2.9	1-2	-	244	-	133	244	67	67	-	-	-	755
63	2	2.3	2-6	177	44	-	66	178	133	-	-	178	-	776
64	2	3.0	1-2	66	44	-	22	-	-	-	-	111	-	243
65	2	2.7	1-2	753	666	-	1421	1243	3707	133	-	155	-	8078
66	2	11.0	2	310	22	-	-	111	-	133	-	-	-	576
71	2	14.0	1-2	2641	-	-	821	466	-	932	-	44	-	4904
72	2	9.0	1	555	-	-	1043	266	-	178	-	-	-	2042
74	1	12.0	1-2	843	-	-	7193	178	-	289	-	688	-	9191
75	2	9.5	1-2	1864	-	-	4484	266	-	-	-	178	-	6792
76	2	7.6	1-2	177	-	-	577	200	-	22	-	-	-	976
77	1	14.5	1-2	1066	-	-	1998	266	-	1066	-	89	-	4485
78	2	14.5	1-2	1510	-	-	4640	266	22	532	44	266	-	7280
AVERAGE				850.	60.	7	1553	378						

APPENDIX TABLE 2. Distribution of Chironomidae in Southern Indian Lake

Station Taxon	1	2	3	4	5	6	10	16	17	19	20	21	22	23	24	25	30	31	32	33	34	35
Procladius (s.s.)	44	178	89	111	133	200	155	178	-	355	200	178	-	178	155	-	22	67	266	155	89	67
Procladius (psil)	44	133	22	111	111	200	67	133	-	133	133	-	-	89	67	244	-	111	133	89	67	22
Clinotanypus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89	-	-	-	-	-	-
Ablabesmyia	-	-	-	-	-	44	-	-	-	22	-	-	-	22	-	-	-	-	-	-	-	-
Protanypus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	89	-
Monodiamesa	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44	-	-	22	-	44	-	-
Trissocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-
Cladotanytarsus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-
Micropsectra	-	-	-	-	-	44	-	-	-	44	-	-	-	-	22	-	22	-	-	22	-	-
Tanytarsus	-	44	-	289	355	488	111	44	-	222	89	-	-	111	311	44	289	22	844	178	266	155
Stempellina	-	-	-	-	-	22	22	-	-	178	-	-	-	-	-	22	-	-	-	-	222	-
Zavrelia	-	-	-	-	-	22	-	-	-	133	-	-	-	22	-	-	-	-	-	133	89	-
Chironomus (s.s.)	-	-	-	89	199	-	-	-	-	44	-	44	44	22	266	-	-	222	2266	-	22	133
Cryptochironomus	-	-	-	22	-	-	22	-	-	-	44	-	-	-	44	-	-	-	44	-	133	22
Demicryptochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dicrotendipes	-	-	-	-	-	-	-	-	-	44	-	-	-	-	-	-	-	-	-	-	-	-
Einfeldia	-	-	-	-	-	-	-	-	-	111	-	-	-	-	-	-	-	-	-	-	-	-
Endochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cryptocladopelma	-	-	-	-	-	-	-	-	-	44	-	-	-	22	-	-	-	-	-	-	22	-
Cryptotendipes	-	22	22	22	-	-	22	-	-	-	-	-	-	44	-	-	-	-	-	-	311	67
Microtendipes	-	-	-	-	-	-	-	-	-	-	-	-	44	-	-	-	-	-	-	-	-	-
Kribioxenus	-	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pagastiella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-	44
Paracladopelma	-	-	22	-	-	-	67	-	-	-	44	-	-	44	67	22	22	-	-	-	22	44
Paralauterborniella	-	-	22	-	-	44	-	-	-	-	-	-	-	-	-	-	-	-	-	-	44	-
Polypedilum	-	22	-	-	-	-	-	-	-	-	-	-	-	67	67	22	-	-	-	-	-	-
Stictochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Chironomini?	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-	-	-	-
Parakiefferiella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22
Psectrocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Orthocladiinae	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-
Unidentified	-	-	-	-	22	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals	88	421	177	644	820	1086	466	355	x	1352	510	222	88	643	1043	487	377	444	3553	621	1376	576

cont.

APPENDIX TABLE 2. Distribution of Chironomidae in Southern Indian Lake

Station Taxon	40	41	42	43	44	45	46	47	48	50	51	52	53	54	55	56	57	58
Procladius (s.s.)	22	289	200	178	155	67	400	421	44	89	67	89	89	22	89	155	89	-
Procladius (psil)	-	89	111	44	-	44	155	422	-	111	67	22	-	-	-	133	22	-
Clinotanypus	-	-	-	-	-	44	-	-	-	-	-	-	-	-	-	-	-	-
Ablabesmyia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-
Protanypus	-	-	-	-	-	-	-	-	-	-	-	-	-	155	-	-	-	22
Monodiamesa	-	178	-	-	-	-	-	-	-	-	67	22	-	-	-	-	67	-
Trissocladius	-	-	-	-	-	932	22	-	-	-	-	-	-	-	-	-	-	-
Cladotanytarsus	-	-	-	44	-	-	-	-	22	-	-	-	22	-	-	-	-	-
Micropsectra	-	67	-	-	-	-	-	-	-	-	22	-	-	-	-	22	-	-
Tanytarsus	-	1021	178	0	0	200	22	222	89	289	22	111	155	1376	22	599	44	-
Stempellina	-	-	22	-	-	-	-	-	22	-	-	-	-	22	-	44	-	-
Zavrelia	-	-	-	-	-	22	-	-	22	67	-	-	-	-	-	67	-	-
Chironomus (s.s.)	66	66	733	-	-	155	2398	2064	-	-	66	177	-	22	66	288	22	-
Cryptochironomus	-	44	-	-	-	-	-	-	44	67	22	-	22	89	-	-	44	22
Demicryptochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-
Dicrotendipes	-	-	-	-	-	67	-	-	-	-	-	-	133	-	-	-	-	-
Einfeldia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Endochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-
Cryptocladopelma	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-	44	22	-
Cryptotendipes	-	-	-	-	-	-	-	-	-	44	-	-	-	511	-	400	-	-
Microtendipes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Kribioxenus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pagastiella	-	-	-	-	-	-	-	-	-	22	-	-	67	488	-	67	-	-
Paracladopelma	-	67	-	44	-	-	-	-	67	-	-	22	-	-	22	-	-	-
Paralauterborniella	-	-	-	-	-	-	-	-	-	-	-	-	-	44	-	-	-	-
Polypedilum	-	-	-	-	-	-	-	-	22	-	22	-	-	-	22	22	-	-
Stictochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	44	-	-	-	-
Chironomini?	-	-	-	-	-	-	-	-	22	-	-	-	-	-	-	-	-	-
Parakiefferiella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Psectrocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	22	-	-	-	-
Orthocladiinae	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Unidentified	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Totals	88	1821	1244	310	155	1531	2997	3129	354	689	377	443	355	2972	221	1863	310	44

cont. APPENDIX TABLE 2. Distribution of Chironomidae in Southern Indian Lake

Station Taxon	60	61	62	63	64	65	66	71	72	74	75	76	77	78	Average
Procladius (s.s.)	-	-	-	67	-	89	67	355	67	222	355	22	311	133	131.5
Procladius (*psil*)	-	44	-	44	-	155	133	111	-	89	222	22	178	67	79.1
Clinotanypus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.5
Ablabesmyia	-	-	-	-	-	44	-	-	-	-	-	-	-	-	2.9
Protanypus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.0
Monodiamesa	-	-	-	-	-	-	-	22	67	44	22	-	-	-	11.3
Trissocladius	-	-	-	-	-	-	-	-	22	-	-	-	-	-	18.8
Cladotanytarsus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.1
Micropsectra	-	-	-	-	-	-	-	22	22	-	-	-	-	89	7.5
Tanytarsus	-	155	-	22	-	89	22	1909	289	400	1110	67	577	1088	263.
Stempellina	-	-	-	-	-	-	-	-	-	-	22	22	-	67	13.0
Zavrelia	-	-	-	-	-	-	-	-	-	-	89	-	-	22	13.0
Chironomus (s.s.)	-	44	-	22	-	-	-	200	-	-	-	22	-	-	184.
Cryptochironomus	-	-	-	-	-	-	-	-	-	44	22	-	-	44	15.0
Demicryptochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.4
Dicrotendipes	22	-	-	-	-	22	-	-	-	-	-	-	-	-	5.4
Einfeldia	-	-	-	-	-	-	-	-	-	-	-	-	-	-	2.1
Endochironomus	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.4
Cryptocladopelma	-	-	-	-	-	22	-	-	-	-	-	-	-	-	3.7
Cryptotendipes	-	-	-	-	44	155	22	-	-	-	-	-	-	-	31.8
Microtendipes	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.8
Kribioxenus	-	-	-	-	-	-	-	-	22	-	-	22	-	-	1.2
Pagastiella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	13.4
Paracladopelma	-	-	-	22	-	-	44	-	-	44	22	-	-	-	13.4
Paralauterborniella	-	22	-	-	-	22	-	-	-	-	-	-	-	-	3.7
Polypedilum	-	-	-	-	-	-	-	-	-	-	-	-	-	-	5.0
Stictochironomus	-	-	-	-	-	133	-	-	44	-	-	-	-	-	4.2
Chironomini?	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.8
Parakiefferiella	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.4
Psectrocladius	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.4
Orthocladiinae	-	-	-	-	-	-	22	-	-	-	-	-	-	-	1.2
Unidentified	-	-	-	-	-	-	-	-	-	-	-	-	-	-	.4
Totals	22	265	nil	177	44	731	310	2619	533	843	1864	177	1066	1510	

APPENDIX 5 - VOL. 1 - H.

THE FISHERIES OF SOUTHERN INDIAN LAKE: PRESENT CONDITIONS AND IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

THE FISHERIES OF SOUTHERN INDIAN LAKE
PRESENT CONDITIONS AND IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

by

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for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

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6.0. SUMMARY

a) The existing data on the fisheries of Southern Indian Lake are presented and discussed, and recommendations with respect to these data are put forward.

b) At least 19 fish species are present in Southern Indian Lake including lake whitefish, northern pike, yellow walleye, sauger, perch, cisco, goldeye and suckers.

c) Whitefish are present in greatest abundance in regions 2, 4 and 5 of Southern Indian Lake. Mean lengths and mean weights of whitefish from region 5 are greater than from elsewhere in the lake. Mean lengths, weights and ages of whitefish are high in region 2 during midsummer, but decrease coincidentally with an increase in these parameters in whitefish in region 4 during late summer. Food of whitefish is predominantly amphipods, sphaeriids and gastropods. There is no evidence of an over-exploitation of the whitefish population by the commercial fishery. Impoundment will increase the size of the whitefish population initially, but the final result will be a population size somewhat less than exists today.

d) Walleye are present in all parts of Southern Indian Lake, but are present in different densities at different times of the summer. Data suggest the walleye are using the Barrington, Muskwesi and Waddi Rivers as well as streams in region 6 for spawning purposes. By late summer the concentrations of spawning walleye have disbursed and growth rate and condition of walleye is similar in all parts of the lake. Food of walleye is predominatly cisco and/or whitefish. Impoundment should not have an adverse effect on stream-spawning walleye providing new spawning sites are available above the high-water level (see Weagle and Baxter, 1973). Change in the flow of the Churchill River could disorient migration patterns.

e) Marked differences in catch per unit effort of northern pike are noted at different stations during different times of the summer. During mid-summer pike from different stations are similar in length and weight but by late summer significant differences in mean lengths and weights suggest segregation into discrete populations. Cisco, whitefish, white sucker and burbot are the main dietary items of pike. Impoundment will have a positive effect on northern pike, with initial increases anticipated in size, condition and number.

f) Cisco in region 7 are significantly larger and older than cisco from elsewhere in Southern Indian Lake. Cisco from the rest of the lake appear to be similar throughout. Mysids are taken most often for food though mayfly nymphs and zooplankton are important. Impoundment could enhance the cisco popuation initially, but final results should be similar to whitefish.

g) Sauger appear to be close to their northern limits in Southern Indian Lake and are reasonably abundant only in regions 1 and 6. Food of sauger is primarily cisco or whitefish, with some trout-perch. Impoundment will likely create new habitat ideal for sauger although until shoreline clearing either by artifical or natural methods is accomplished availability of spawning sites is questionable.

h) White sucker are present in most areas of Southern Indian Lake at depths down to 70 feet. Longnose sucker are more prevalent in the main lake regions. Probably neither of these species will be adversely affected by the flooding and diversion. New lake conditions should be an improvement for yellow perch and areas that are now devoid of this species (areas of strong river flow) should contain perch. Neither trout-perch nor burbot occur in large quantities in Southern Indian Lake and there will likely be little change in their numbers following impoundment.

i) Recommendations include

1) Future water level fluctuations to follow historical pattern of fluctuation in Southern Indian Lake.
2) Sites for future spawning beds for specific fish species be prepared prior to flooding.
3) Continued study of Southern Indian Lake to monitor changes in fish dynamics.

6.1. INTRODUCTION

This portion of the fisheries program of the Lake Winnipeg, Churchill and Nelson Rivers Study was originally charged with the task of studying the dynamics of the fish population of Southern Indian Lake, including the collection of data pertinent to species composition, distribution, growth, food, and condition. This report attempts to summarize the data gathered, to highlight particular information which exemplifies aspects of the existing population as it was found and to put forward recommendations for the fishery that arise from the existing data.

This report is restricted to the fisheries of Southern Indian Lake and Opachaunau Lake. It does not deal with the commercial or sports fishing complex of Southern Indian Lake. Data for this report is exclusively from the results of the 1972 summer field program with comparisons made where appropriate to the work done in 1952 on Southern Indian Lake by W. McTavish.

The report is broken down into components consisting of the individual fish species. Discussion of each species is limited by the amount of information available; and, indirectly, by the economic importance of the species to the area. Where the amount of data and general biological information on the species is great enough the implications of the hydro proposal on a fish species has been discussed. Finally, conclusions and recommendations to minimize fishery disbenefits based on the above are put forward.

6.2. METHODS

6.2.1. Fish sampling:

Fishing was carried out in the 7 major regions of the lake throughout the summer of 1972 at individual stations within each region (Figures 1 and 2). Three "trips" through the seven regions were completed during the summer with stations 10, 20, 30, 40, 50 and 60 being visited at each trip. All other stations were fished at least once, some twice. The dates for the three trips were; trip I July 1-17; trip II August 9-26; and trip III August 30 to September 9.

Two types of nets were used for most sets. The standard gang, used consistently throughout the study consisted of 6 multi-filament nylon nets, each 50 yards long of the following size and order (stretch mesh): 5 1/4", 1 1/2", 4 1/4", 2", 3 1/2", 2 3/4". Usually, two gangs were set at a station, one in shallow water (3-7 meters) and one in deep (greater than 8 meters). The second type of net, a "Swedish" net, is a specially designed single test monofilament net consisting of 12 combined mesh sizes from 3/4" to 6" (stretch mesh) each 10 feet long. This net was set with each gang of regular nets where possible. It proved to be considerably more fragile than the regular nets and could not be set in rough weather conditions. All sets were bottom sets left in overnight and the depths at both ends of each mesh were recorded. At the time of set the temperature profile (surface to bottom) was recorded.

Species, fork lengths, weights, and sex were taken and recorded for all fish captured. Scale samples and stomach samples were taken from the first ten fish of each species in each mesh. The stomach samples were preserved in 10% formalin.

For greater detail of field methods see Appendix.

6.2.2. Stomach samples:

In the field, stomachs were removed from the first ten fish of each species in each mesh. Stomachs from northern pike, yellow walleye, burbot, and sauger were opened and if empty were noted as such on the scale envelope and discarded. Preliminary analysis was carried out in the field providing it was possible to positively identify the specimens as well as record the weight.

The bulk of the sampled stomachs were preserved in formalin and returned to the lab for detailed analysis. The samples were soaked in water for several hours prior to examination then all liquid drained off. For each species at each station the wet weights of each type of food organism were pooled and the percent of the total represented by each type, was calculated. Stomachs of whitefish, cisco, pike, walleye, sauger, perch and burbot were examined. Because of the degree of difficulty in identifying stomach contents of suckers, they were not examined at this time.

Unless unrecognizable because of the degree of digestion (unidentified fish or unidentified invertebrate), all organisms were identified and wet weights taken (2/3 of the weight of molluscs was removed to allow for shell weight). Fish, mysids, and amphipods were identified to species; sphaeriids to genus; gastropods and copepods to family; and chironomid larvae, mayfly nymphs, caddis larvae and cladocera to order. Items included

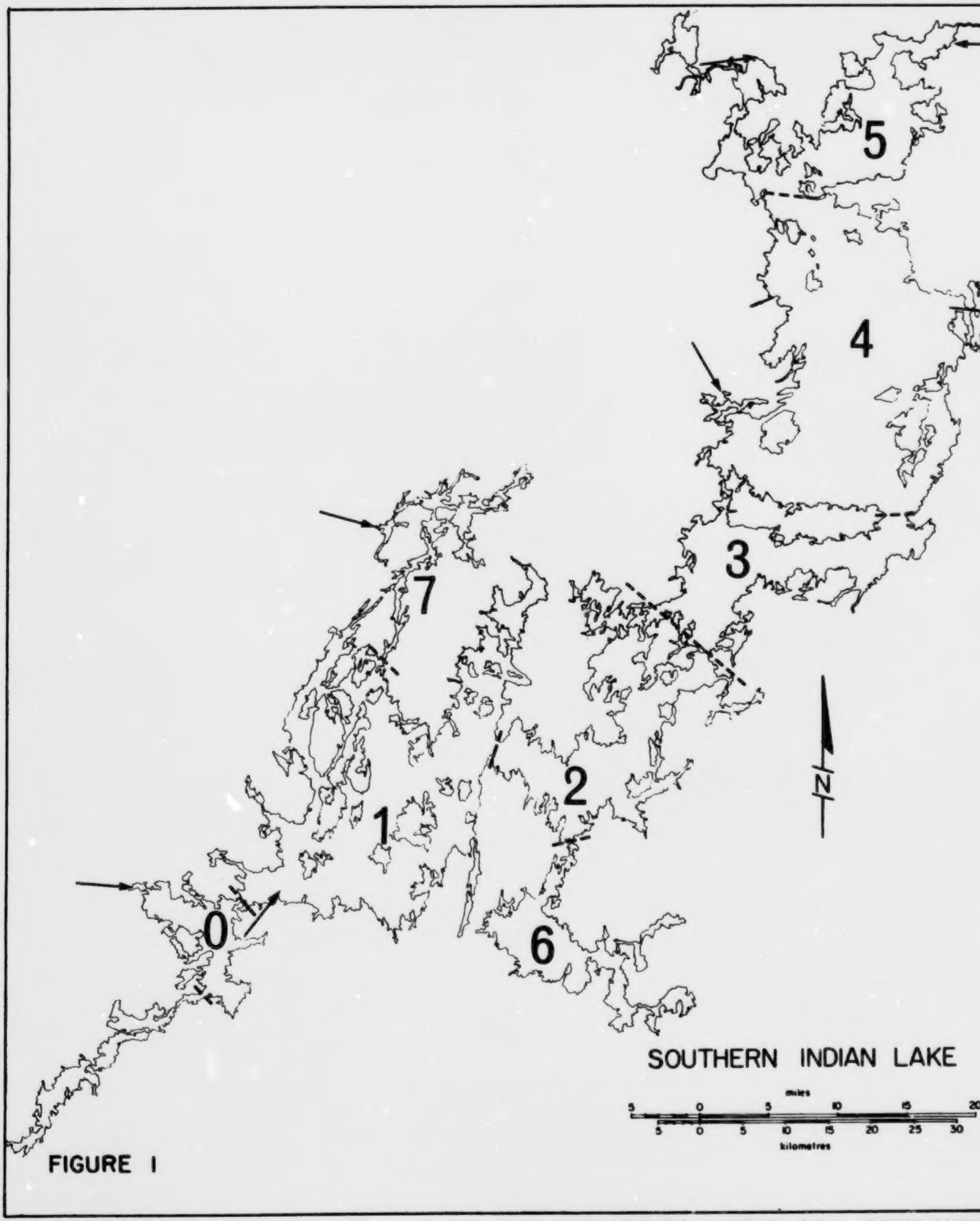
5
4
3
7
2
1
0
6
N
SOUTHERN INDIAN LAKE
miles
5
0
5
10
15
20
5
0
5
10
15
20
25
30
kilometres

FIGURE I

GEOGRAPHIC REGIONS SET UP BY THE FISHERIES-LIMNOLOGY COMPONE

(note: arrows indicate direction of flow of major streams)

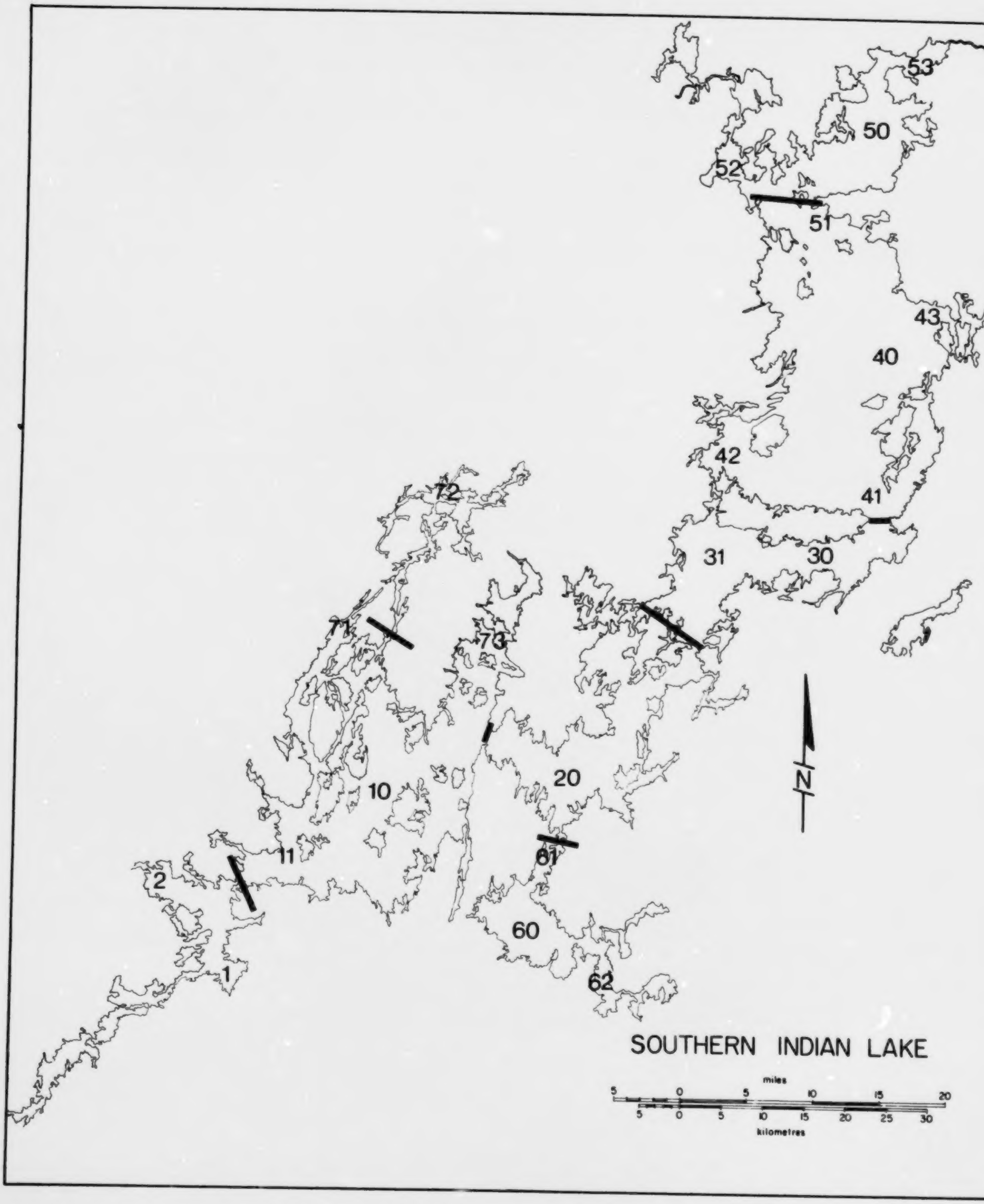
53
50
52
51
43
40
42
41
72
31
30
71
73
20
10
11
61
2
60
1
62
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

FIGURE 2. FISHING STATIONS ON SOUTHERN INDIAN LAKE, 1972.

originally under the title miscellaneous were bottom detritus, iron nodules sand, gravel, phytoplankton, and unidentified terrestrial insects.

6.2.3. Age determination:

For the purpose of determining growth curves in this study ages of fish were considered to be the same as the number of true annuli or rings appearing on the fish scale. Carlander (1956) states that this is a valid assumption provided that the possible presence of false annuli is recognize

While the scales removed from the fish were not key scales, they were removed from the same area on each species. Scales were aged by two people although each completed an entire trip for any one species, and usually completed the aging for an entire species. It is felt that between the two people, the ages assigned to be five years or under were the same better than 95% of the time. The similarity of those assigned older years could drop to 50% although the discrepancy was rarely greater than ± 1 year. Measurements of scale radius and distance between annuli were recorde on paper tape for later measurement.

Mean lengths and standard error at each age were calculated for each major species of fish at each station.

6.2.4. Back calculation:

The validity of body length-scale size relationships is usually dependent upon the assumption that the scale radius increases in size in direct proportion to the body length of the fish. Scale samples removed must be key scales i.e. the same scales from each fish, or at least, as supported by Dryer (1963) from the same area on the fish.

Body-scale relationships in this study, for the two commercial species of fish (whitefish and walleye) have been considered to be linear as is the case in all literature cited here. Carlander (1956) states that in actual fact the relationship in every population is probably curvilinear but that there is a greater opportunity to introduce error in attempting to describe the curvilinear relationship than there would be in making the assumption that the relationship is linear.

The formula used for calculation was:

$$ln - c = \frac{sn}{s}(l - c) \qquad \text{(Tesch 1971)}$$

where: ln = fork length of fish at given annulus
l = fork length of fish at time of sampling
sn = radius of given annulus
s = total scale radius
c = correction

The correction factor is required where the relationship between fork length scale radius is linear, but not directly proportional. This 'C' value, defined as the intercept on the length axis from a least-squares fit of the length:radius data is considered by most to be the length of the fish at scale formation. Hile (1970) cautions that this is not a correct assumpt although the 'C' value often is near to the length of the fish when scales are formed.

With the Southern Indian Lake data, 'C' values were calculated from whitefish data at the major stations. In one case where the number of samples was too small to be fitted to a regression line an intercept value was assigned based on an average of the other calculated 'C' values

The data from walleye could not be shown to be linear, althou this problem does not seem to appear in the literature. The problem probably lies in the fact that the positioning on the scale for meas was not as consistent as could have been. To alleviate this problem value derived from the literature (Glenn, 1969) was assigned to all samples. Once the 'C' value had been assigned the position of meas of the scale becomes meaningless since the length calculations are b on a ratio between annulus and radius measurements. However, by as a 'C' value the opportunity to compare back calculated lengths from data with those from data taken elsewhere is precluded.

6.2.5. Length-frequency composition:

The number of each species that fell in one inch length inte was plotted for most stations on each trip. Although the number an of sets were about the same for each station and each trip, the act numbers of fish within each size range were not considered for comp Instead, the relative numbers and the position of the highest frequ the inch intervals were utilized as the basis for comparison.

6.2.6. Growth rate:

Growth rates were calculated for the major species by fittin linear regression to age and length of fish collected during the fi trips. For each species an analysis of covariance was used to calc the significance of differences in elevations and slopes of regress lines. Level of significance was $p = 0.05$. Differences in slope i differences in growth rate while differences in elevation of the re lines indicates differences in length at age.

6.2.7. Condition:

The relationship between length and weight of a fish is a measur of the plumpness or condition of the fish. Within a species, differenc in the condition of fish of different areas is indicative of population differences between those areas.

Length-weight relationships of the major species were determined by fitting a log-log linear regression to the data. Slopes, elevations and mean lengths were tested for significant differences in the same man as was outlined for growth rate data. Condition regressions are commonl calculated in metric units (grams, millimeters) and Southern Indian Lake data were converted to metric to facilitate comparisons. The condition for the productivity ratings was calculated using the formula:

$$\text{Factor} = \frac{\text{Weight (grams)} \times 10^5}{\text{Length (millimeters)}^3} \qquad \text{(Carlander 1969)}$$

6.2.8. Catch per unit effort:

Although all gillnet sets were made for approximately equal lengt of time, to give a more precise representation of fishing effort the duration of all sets were adjusted mathematically to 16 hours. The basi unit of catch per unit effort is thus the total number of fish caught in gang of nets in 16 hours. Catch per unit effort, for a particular mesh, was determined for walleye and whitefish and was based on the fish caught in a net of that mesh in the standard gang nets.

6.3. SPECIES COMPOSITION

Fish species found in Southern Indian Lake in 1972 are listed Table 1. Though, as the list indicates, the species diversification large, there were undoubtedly species missed. McTavish (1952) did n find spoonhead sculpin, lake chub, longnose dace, bluntnose darter a brook stickleback but he did take samples of two other species, john darter (*Boleosoma nigreen*)[1] and lake or emerald shiner (*Notropis ath* and noted the possible presence of lake sturgeon (*Acipenser fulvesce* and goldeye *Hiodon alosoides*. McTavish also records the presen two species of cisco (*Leucichthys tullibee* and *Leucichthys zenithicu* (shortjaw cisco)). The first, *L. tullibee*,is usually considered to synonym of *Coregonus artedii* (McPhail & Lindsey, 1970). The fishing on Southern Indian Lake in 1972 recorded only *C. artedii*, however, observations of two size groups of ciscoes at sexual maturity were m particularly from region 7. McPhail and Lindsey (1970) note also th presence of two size groups of cisco from various lakes in northern and suggest that one of them is *C. artedii* while the other is more l a member of the *Coregonus sardinella* complex (least cisco).

Fish species compositions of lakes elsewhere in the Churchill drainage are presented in Table 1 . The predominance of the lake sh in other lakes in the Churchill drainage suggests the possibility th this species is present in Southern Indian Lake but was missed in the investigation. The presence of longnose dace in Southern Indian should perhaps be noted. Rawson (1960) found this species in Otter Lake as well as other lakes in that immediate vicinity but he felt it was rare elsewhere in the Churchill drainage.

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[1] American Fisheries Society lists the scientific name of johnny d as *Etheostoma nigrum.*

Table 1. Occurrences of fish species in six lakes in the Churchill drainage basin.

	Lake whitefish (*Coregonus clupeaformis*)	Round whitefish (*Prosopium cylindraceum*)	Cisco (*Coregonus artedii*)	Longnose sucker (*Catostomus catostomus*)	White sucker (*Catostomus commersoni*)	Redhorse sucker (*Moxostoma aureolum*)	Yellow walleye (*Stizostedion vitreum vitreum*)	Sauger (*Stizostedion canadense*)	Yellow perch (*Perca fluviatilis*)	Northern pike (*Esox lucius*)	Burbot (*Lota lota*)	Goldeye (*Hiodon alosoides*)	Lake trout (*Salvelinus namaycush*)	Spot-tail shiner (*Notropis hudsonius*)	Lake shiner (*Notropis atherinoides*)	Ninespine stickleback (*Pungitius pungitius*)	Slimy sculpin (*Cottus cognatus*)	Iowa darter (*Etheostoma exile*)	Trout-perch (*Percopsis omiscomaycus*)	Spoonhead sculpin (*Cottus ricei*)	Brook stickleback (*Culaea inconstans*)	Longnose dace (*Rhinichthys cataractae*)	Lake chub (*Couesius plumbeus*)	Johnny darter (*Etheostoma nigrum*)	Logperch (*Percina caprodes*)	Fathead minnow (*Pimephales promelas*)	Blacknose shiner (*Notropis heterolepis*)	Deepwater sculpin (*Myoxocephalus quadricornis*)	Grayling (*Thymallus areticus*)
Southern Indian 1972	x		x	x	x		x	x	x	x	x	x		x		x	x	x	x	x	x	x	x						
Southern Indian[a] 1952	x		x	x	x		x	x	x	x	x	x		x	x	x	x		x					x					
Lac la Ronge[b]	x		x	x	x		x		x	x	x		x	x		x	x	x	x		x		x						
Wollaston[c]	x	x	x	x	x				x	x	x		x	x	x	x	x		x	x			x				x	x	
Otter[d]	x		x	x	x	x	x	x	x	x	x			x	x	x	x	x	x		x	x	x		x	x		x	x
Churchill[e]	x		x	x	x		x		x	x	x		x	x	x	x	x	x							x	x			
Ile a la Crosse[e]	x		x	x	x		x		x	x	x		x	x	x	x	x	x	x						x	x			

a -from McTavish (1952; b from Rawson & Atton (1953); c from Rawson (1959); d from Rawson (1960; e from Rawson (1957)

6.4. FISH PRODUCTION

The catch per unit effort (C.U.E.) for fish species in different regions of Southern Indian Lake varies according to the species and habitat available in particular regions of the lake (Figure 3). Numbers of whitefish and white sucker in the main lake stations (1, 2, 3 and 4) suggest a positive response to the flow of the Churchill River through the lake. Conversely a fish such as the yellow perch could be expected to be more plentiful in areas of the lake where flow was not particularly evident. The C.U.E. for walleye is likely more consistent throughout the lake than is represented in Figure 3. High values in regions 0, 5, 6 and 7 have been influenced by very high concentrations of walleye found in these regions during the time of spawning.

Catch per unit effort alone cannot be assumed to represent production. To assess the quality of fish, mean weights of each fish species were applied to the mean number of fish caught in a net to give catch per unit effort in pounds (Table 2) which represented production. Production of all fish species was high in the main lake regions and region 5, and was lower in two regions not directly receiving the Churchill flow.

6.4.1. Implication of flooding and diversion on fish production:

An attempt has been made to describe possible effects of both the flooding and the diversion on some of the major fish species in Southern Indian Lake (Table 3). The effects to the lake must necessarily be described in general terms and hence predicted effects on a fish species must be generalizations also. Negative impacts were not recorded for regions where, prior to impoundment, a fish species was in low concentrations.

As suggested by Table 3 the anticipated effects prior to shoreline stabilization for all but pike and possibly sauger will be an overall decrease in fish production.

Based on changes to regions 3, 4 and 6 by the action of diversion as predicted by Hecky _et_. _al_. (1974), Patalas (1974) and Hamilton (1974) an attempt to predict the changes to the commerically important fish species (whitefish and walleye) has been made. These predictions are related to the diversion only, and have been made with the following assumptions in mind;

2) that the productivity of whitefish and walleye will decline as the productivity of lower trophic levels declines, although not necessarily in proportion to their decline, and

b) that although the diversion will increase the rate of turnover in region 6 substantially, it will also increase the biological production of the region to a level similar to region 2 on a unit area basis.

From the table it can be seen that, within approximately 20 years production of walleye and whitefish will likely decline in regions 3 and 4, although production of whitefish will increase in region 6, relative to that in existence at present.

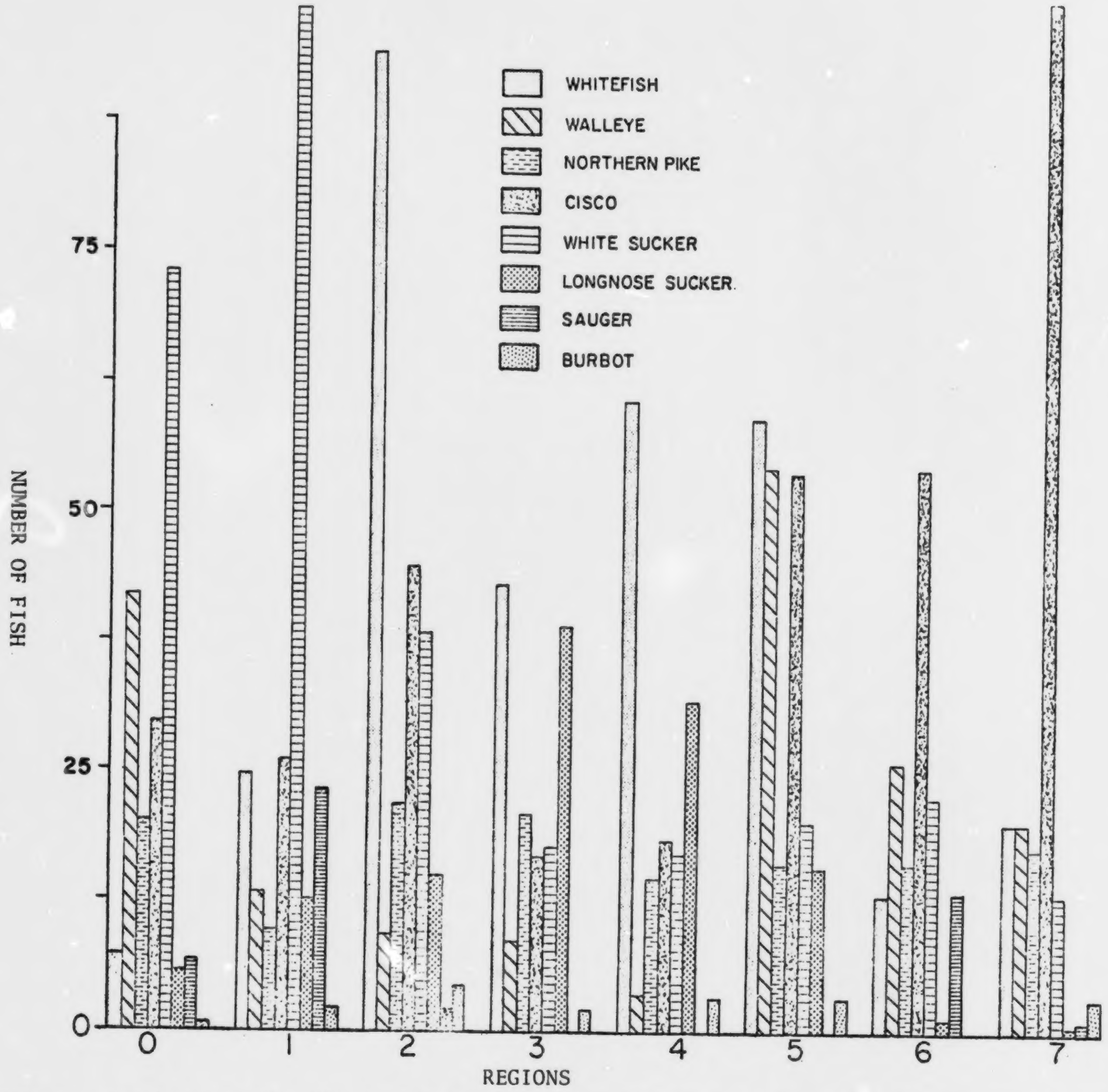


Figure 3. Catch per unit effort of 8 species of fish from 8 regions in Southern Indian Lake, 1972.

Table 2. Mean catch per unit effort in pounds of fish from a single gang of nets from seven regions of Southern Indian Lake, 1972. Estimate of catch per unit effort following diversion (Post) for whitefish and walleye appears in brackets.

Region	Area (Acres)	Whitefish		Walleye		Pike	Cisco	White Sucker	Longnose Sucker	Sauger	Burbot	Total
		(pre)	(post)	(pre)	(post)							
1	117	25	(25)	13	(13)	28	8	148	22	7	6	257
2	55	113	(113)	7	(7)	52	18	135	42	1	9	377
3	49	43	(34)	7	(6)	61	7	34	117	-	16	285
4	155	80	(64)	3	(2)	38	6	27	70	-	8	232
5	52	100	(100)	74	(74)	42	11	42	42	-	9	320
6	29	13	(70)	29	(32)	31	17	41	1	6	-	138
7	12	30	(30)	30	(30)	51	52	20	2	1	10	196

Table 3. Anticipated impacts of flooding and diversion on productivity of particular fish species in Southern Indian Lake, prior to shoreline stabilization. The number of symbols is to denote relative differences and is not to suggest absolute numbers; the sign denotes expected direction of impact.

Region	Development	Anticipated Effect	Anticipated Relative Effect					
			Whitefish	Walleye	Pike	Cisco	Sauger	Other
1	Flooding	Altered near-shore habitat	-	-		-	+	-
		Altered lake spawning habitat	-		++	--	-	
2 (east)	Flooding	Altered near-shore habitat	-	-		-	+	-
		Altered lake-spawning habitat	--		++	--	-	
2 (west)	Flooding	Altered near-shore habitat	-	-		-	+	-
		Altered lake-spawning habitat	--		++	--	-	
	Diversion	Decreased flushing time	-	-	-	-	-	-
		Disoriented migration	--	-				
3	Flooding	Altered near-shore habitat	-	-		-	+	-
		Altered lake-spawning habitat	-	++				
	Diversion	Decreased primary production	--	-	-	--	-	--
		Increased lake habitat	++	+	++	++	+	+
4	Flooding	Altered near-shore habitat	-	-		-	+	-
		Altered lake-spawning habitat	---		++	-		
	Diversion	Decreased primary production	--	-	-	--		--
		Disoriented migration	---					
5	Flooding	Altered near-shore habitat	-	--		-	+	-
		Altered lake spawning habitat	-		++	--		
6	Flooding	Altered near-shore habitat		--		-	+	-
		Altered lake-spawning habitat			++	-	-	
	Diversion	Increased primary productivity	++	+	+	++	+	++
7	Flooding	Altered near-shore habitat	-	-		-	+	-
		Altered lake spawning habitat	-		+	--	-	

6.5. WHITEFISH

6.5.1. Back calculation:

Van Oosten (1923) and Dryer (1963) both found a linear body length-scale radius relationship for whitefish with the intercept at 0 Edsall (1960), Kennedy (1943), and Carlander (1969) found the relationship to be linear with a positive intercept. Regression analyses of this study's data indicate a linear fit with an intercept of between 32 to 40 mm depending upon the area from which the fish were taken. At some stations where the number of samples was very small, the average intercept from all other stations was used for the back calculations.

In a lake such as Southern Indian **where there** is significant commercial fishing the selective fishing mortality might be expected to result in a situation in which "back calculations of length ... exhibit a tendency for computed lengths at a given age to be smaller, the older the fish from which they are computed" (Lee's phenomenon, Tesch, 1971). However, there is no evidence of "Lee's phenomenon" occurring in any of the areas (Table 2) whether they have been fished, commercially, or not. Thus, this calculation gives no evidence of selective fishing mortality i.e. no evidence of over-exploitation by the commercial fishery.

As will be discussed in the section on growth rate (Section 6.5.3) annual increments of length calculated from scale measurements at any one age differ from station to station. Whitefish taken from stations 50 and 20 had greater average annual increments than did those from other stations even though whitefish from station 20 were smaller than those from station

30 at the formation of the first annulus. Length at the time of first annulus formation is significantly greater at station 50 than station 40 (t = 8.04, df 184). This suggests that whitefish in region 5 have an early advantage in growth over those in region 4. This is supported by evidence discussed in the section on growth rate where the same observation is made from actual, not back calculated data. The same does not hold true for comparisons between actual and back calculated data during the first years at both stations 30 and 60. From back calculations, the size at age 1 of whitefish sampled from stations 30 and 60 is greater relative to values calculated at other stations and relative to values taken from fish aged 1 year. From age-length information, however, the annual increments decrease at a greater rate at stations 30 and 60 than those at other stations. Thus it appears that whitefish at these two locations could have an early advantage for growth, but following this initial increase the subsequent growth is too slow for the advantage to remain evident.

6.5.2. Age, length frequency:

Depending upon the time of the year and the area of the lake, there were several dominant length classes occurring in Southern Indian Lake (Figure 4). During trips I and II at stations 10, 20, 30, 40 and 60 the dominant length classes were indicative of fish between 3 and 6 years, with no particular age the strongest consistently throughout the lake. At station 50, the dominant length probably consisted of fish about 8 years at all three sampling times.

Data collected during trip III indicate that a shift in location of

Table 4. Back calculated fork lengths at the time of each annulus formation for each age group of whitefish from 6 different stations on Southern Indian Lake. Average fork lengths and annual increments for all age groups are included.

AGE AT CAPTURE	NO. OF FISH	FORK LENGTH (INCHES) AT ANNULUS FORMATION											
		1	2	3	4	5	6	7	8	9	10	11	12
Station 10													
5 +	3	4.3	5.9	7.8	9.8	11.8							
6 +	2	3.5	5.4	7.0	8.4	9.7	10.8						
7 +	3	3.3	4.8	6.5	8.0	9.2	10.4	11.7					
8 +	1	3.2	4.7	6.2	8.7	9.7	12.1	13.7	14.9				
Ave. Fork Length		3.6	5.2	6.9	8.7	10.1	11.1	12.7	14.9				
Annual Increments		3.6	1.6	1.7	1.8	1.4	1.0	1.6	2.2				
Station 20													
1 +	4	3.5											
2 +	6	3.3	5.4										
3 +	8	3.2	5.2	7.0									
4 +	10	3.5	5.4	7.2	8.7								
5 +	5	3.2	5.2	6.8	8.3	9.8							
6 +	12	3.3	5.3	6.8	8.7	10.7	12.6						
7 +	12	3.3	4.9	6.4	8.0	9.8	11.5	13.0					
8 +	1	3.7	5.9	7.4	8.5	10.9	12.4	13.9	15.5				
9 +	4	3.0	4.7	6.4	8.0	9.5	11.0	12.4	14.0	15.8			
10 +	1	3.1	4.3	6.4	7.6	9.1	11.1	13.3	15.0	16.4	18.0		
Ave. Fork Length		3.3	5.1	6.8	8.3	9.9	11.7	13.2	14.8	16.1	18.0		
Annual Increments		3.3	1.8	1.7	1.5	1.6	1.8	1.5	1.6	1.3	1.9		
Station 30													
2 +	4	3.9	5.7										
3 +	2	4.2	5.8	7.0									
4 +	10	3.7	5.3	6.7	7.9								
5 +	4	4.2	5.6	7.0	8.3	9.5							
6 +	4	3.7	5.3	6.9	8.5	9.8	11.1						
7 +	3	3.1	4.5	5.6	6.7	8.1	9.1	10.2					
8 +	5	3.7	5.4	6.8	8.3	10.0	11.6	12.8	13.8				
10 +	2	3.3	5.4	7.2	8.6	10.0	11.3	12.3	13.4	14.8	16.4		
11 +	6	3.9	5.4	6.7	8.1	9.2	10.3	11.7	10.7	14.2	15.4	16.4	
12 +	4	3.5	5.0	6.3	7.5	8.7	10.1	11.1	12.3	13.4	14.4	15.3	16.3
Ave. Fork Length		3.7	5.3	6.7	8.0	9.3	10.6	11.6	12.5	14.1	15.4	15.8	16.3
Annual Increments		3.7	1.5	1.4	1.3	1.3	1.3	1.0	0.9	1.6	1.3	0.4	0.5
Station 40													
2 +	6	3.7	5.2										
3 +	7	3.1	4.7	6.1									
4 +	1	3.5	5.4	6.7	7.9								
5 +	7	3.6	5.2	6.7	8.3	9.5							
6 +	6	3.4	4.8	6.1	7.8	9.1	10.3						
7 +	3	3.5	5.1	6.6	8.5	10.7	12.2	13.9					
8 +	17	3.4	4.9	6.4	7.8	9.3	10.6	12.0	13.9				
9 +	20	3.3	4.8	6.3	7.8	9.3	10.6	11.6	13.3	14.5			
10 +	17	3.2	4.7	6.1	7.6	9.2	10.5	11.7	13.0	14.2	16.4		
11 +	10	3.6	5.2	6.5	7.9	9.1	10.4	11.7	13.0	14.3	15.5	16.6	
12 +	1	3.9	5.0	5.8	6.8	8.0	9.0	10.7	12.2	12.9	13.8	14.8	
Ave. Fork Length		3.4	5.0	6.3	7.8	9.3	10.5	11.8	12.8	13.8	14.9	15.2	14.8
Annual Increments		3.4	1.6	1.3	1.5	1.5	1.2	1.3	1.0	1.0	1.1	0.3	-
Station 50													
3 +	3	3.9	5.5	6.9									
4 +	5	4.2	5.9	7.6	8.4								
5 +	7	4.3	5.9	7.5	8.8	10.2							
6 +	17	4.0	5.8	7.6	9.2	10.8	12.1						
7 +	15	3.9	5.4	7.1	8.1	10.6	12.4	13.6					
8 +	12	4.0	5.6	7.1	8.7	10.4	12.1	13.9	15.4				
9 +	19	4.0	5.6	7.0	8.6	10.2	11.1	13.4	14.9	16.0			
10 +	16	3.7	5.3	7.0	8.7	10.6	12.2	13.8	15.3	16.7	16.7		
11 +	7	3.9	5.7	7.4	8.7	10.0	11.4	12.8	14.0	15.2	16.6	17.8	
12 +	1	3.4	4.9	6.4	8.5	10.0	11.5	12.6	13.9	16.7	18.0	19.0	
Ave. Fork Length		3.9	5.6	7.1	8.6	10.3	11.8	13.3	14.7	16.1	17.1	18.4	
Annual Increments		3.9	1.7	1.5	1.5	1.7	1.5	1.5	1.4	1.4	1.0	1.3	
Station 60													
1 +	1	3.9											
2 +	2	3.9	5.6										
3 +	3	3.6	4.9	6.1									
4 +	2	3.9	5.7	7.8	9.2								
5 +	2	4.5	6.0	7.4	9.1	10.6							
6 +	2	3.9	5.2	6.8	8.2	9.5	10.8						
7 +	4	4.3	5.7	7.1	8.5	9.8	11.5	13.0					
8 +	3	4.2	5.4	6.9	8.1	9.8	11.4	12.8	14.0				
9 +	1	3.8	5.3	7.0	9.0	10.4	12.0	13.2	14.1	15.9			
10 +	1	3.5	4.8	5.9	6.9	8.3	9.3	11.0	12.5	13.6	14.8		
11 +	1	4.0	5.0	5.9	6.9	8.0	8.9	10.4	11.7	12.6	13.6	14.4	
Ave. Fork Length		3.9	5.4	6.8	8.2	9.5	10.6	12.1	13.1	14.0	14.2	14.4	
Annual Increments		3.9	1.5	1.4	1.4	1.3	1.1	1.5	1.0	0.9	0.2	0.2	

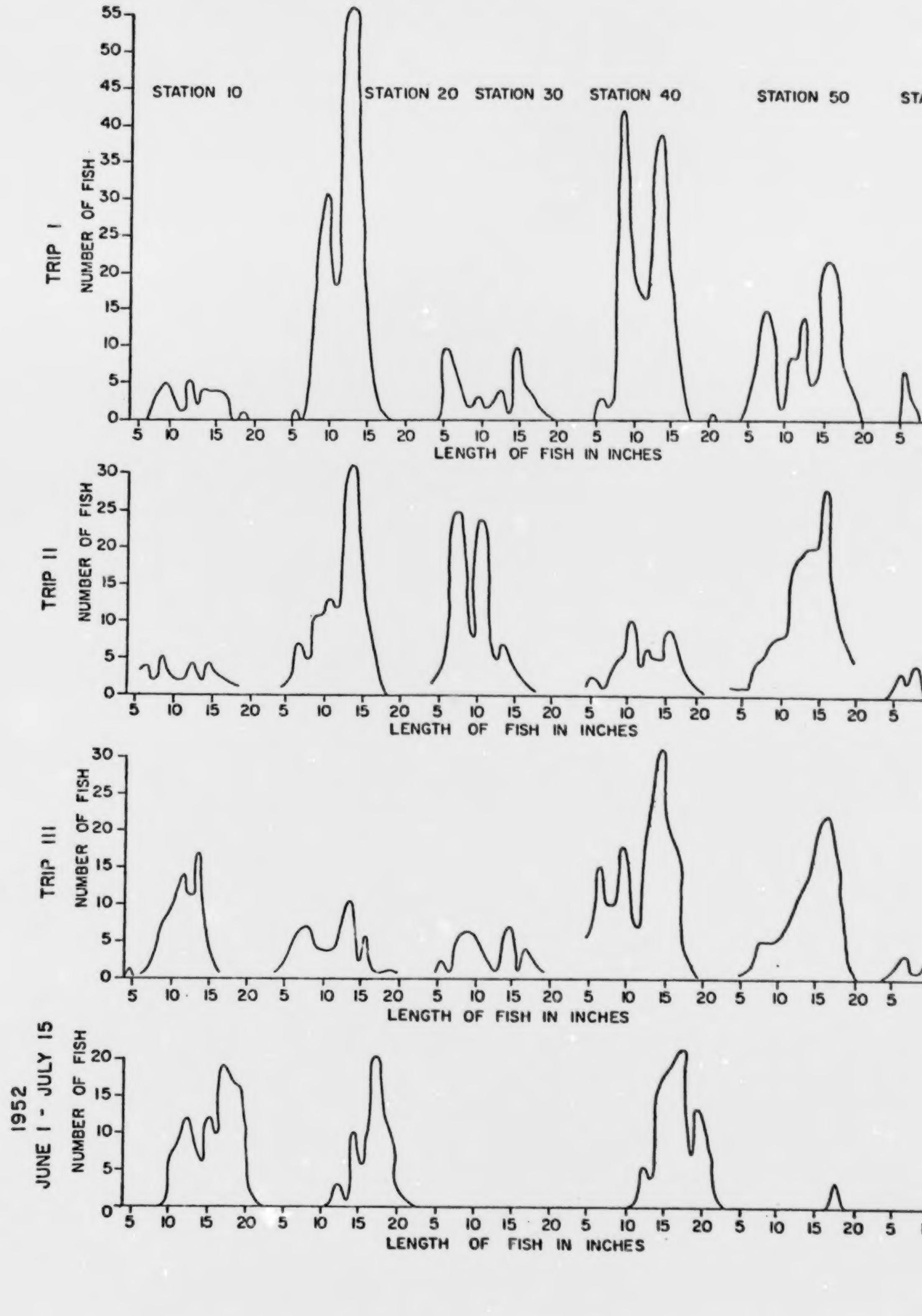
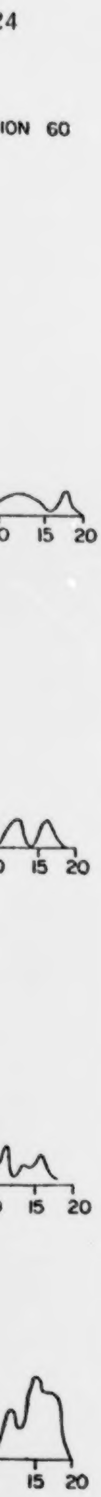


Figure 4. Length-frequency composition of whitefish in Southern Indian Lake, during 1952 and during 3 trips in 1972.



the predominant peak occurs at station 40 and to a lesser degree at stati
30. Because of the difficulty in replicating exact fishing locations the
is a possibility that choice of location could affect results. However,
is unlikely that relative numbers between older year classes could be affected by fishing locations. Instead it is felt that this shift could
a movement into these areas of fish about to spawn. Weagle and Baxter (1
that spawning whitefish in Southern Indian Lake average 8.9 years and Qa
(1968) states that spawning whitefish in Lac la Ronge are 8 years and ove
Qadri (1968) reports migration to spawning grounds in Lac la Ronge and Kennedy (1954) found movement to be as far as 30 miles to spawning areas
Lake Winnipeg. The shift in relative numbers at station 40 was to the length of fish that could be expected to be 8 years from a length corresponding to the 5 year olds. This was observed at a time of year (Septemb
7) when some migration for spawning could be expected.

Data taken from McTavish (1952) in Figure 4 suggest that the year class structure in 1952 differs from the present one. In general, the fis
caught by McTavish were longer than those caught in 1972. In a comparison
between fish caught in comparable mesh sizes in 1952 and 1972 (Table 6) th
were even greater differences in the smaller 2 3/4" mesh than in the 5 1/4
mesh.

L. Sunde (pers comm) suggests that this discrepancy could be the result of two influences:

1. Though the winter fishery had been in operation since 1941 the summ
fishery had just been initiated at the time of McTavish's investigation so that the fish population at that time was less exploited relative to the

found

Table 5. Mean lengths at age of whitefish from 7 stations during trip on Southern Indian Lake, 1972.

Station \ Age (years)	3	4	5	6	7	8
10	7.8	9.2	11.8	12.1	13.3	15.7
20	8.8	10.2	12.6	14.0	14.7	16.0
30	8.3	9.1	11.0	11.2	12.6	14.2
40	8.1	9.5	10.8	11.6	14.7	15.2
50	8.1	10.4	12.1	14.2	15.4	15.8
60	7.9	-	-	12.2	-	-
71	8.8	9.5	12.0	13.8	14.3	16.1

fish population of 1972. From his experience Mr. Sunde has found that a unexploited fishery has a tendency to "stock pile" fish of many year classes all at the same size and that these fish crowd the gillnet biasi the results towards one length class. After regular commercial exploita of a fishery over a number of years this "stock pile" would be depleted gillnet meshes of different sizes would show a larger variation of lengt frequencies.

2. Although McTavish used nylon gillnets, it had been about 1952 tha the switch from cotton to nylon twine had taken place and the nylon twin was the same thickness as the older cotton twine and much thicker than today's nylon twine. The 2 3/4" mesh particularly of thicker twine is capable of gilling and holding much larger whitefish (of 5 to 6 pounds) the head, biasing the sample taken.

It appears then that commercial fishing could account for the app decrease in mean lengths and weights of whitefish in Southern Indian Lak but that these decreases are not the effect of over-exploitation by the fishery. Although the commercial fishing has probably removed the large whitefish (jumbo's) that were once said to exist in this lake, from the information on back calculation (Section 6.5.1) as well as in this secti there is no evidence to suggest that over-exploitation of the fish stock of Southern Indian Lake is occurring.

6.5.3. Growth rate, age and lengths:

The age-length data of whitefish from trips II and III were plott to compare rates of growth of these fish in different areas of the lake

Table 6. Mean weights and mean lengths of whitefish from Southern Indian Lake taken from 2 sizes of gillnets in 1952 (McTavish) and 1972.

	Stations							
	10		30		40		60	
	1952	1972	1952	1972	1952	1972	1952	1972
2 3/4" Mesh								
Mean weight (pounds)	1.8	0.7	2.9	1.2	3.4	0.7	2.2	1.4
Mean length (inches)	14.5	10.8	17.0	12.2	16.9	11.0	14.8	13.4
5 1/4" Mesh								
Mean weight (pounds)	3.6	3.0	3.0	2.7	3.2	2.0	-	-
Mean length (inches)	17.9	17.0	18.1	16.9	17.6	15.9	-	-

observed at different times of the growing season. The trip II data include information from the major station plus station 71, trip III data only from the major stations (Figure 5).

Growth curves from data taken during trip II show that there were no significant differences between rates of growth of fish at the 7 stations. However, there were significant differences between the elevations of the growth curves of particular stations. Growth curves from both stations 50 and 20 were significantly higher in elevation than the other major stations. Since the rate of growth of fish in this area was not greater, an early advantage in growth could account for the substantially higher elevations. Station 71 also had a significantly higher elevation than did stations 30 and 60.

The results of the third trip show that the whitefish that were taken from station 20 had a significantly faster growth rate than did whitefish from other stations. As in trip II whitefish taken from station 50 were larger at age and appear to have had an early advantage in growth. For this trip whitefish taken from station 10 were also larger.

From these data it appears that while there was little difference in the rate of growth between different regions some areas do appear to have an advantage in the first years. This apparent early advantage of whitefish from station 50 is discussed from a different aspect and in more detail in section 6.5.1. (Back-Calculation).

The unique significantly different growth rate at station 20 as observed during trip III could be the result of movement out of the region, of the older, usually more slowly growing whitefish (Dryer 1963)

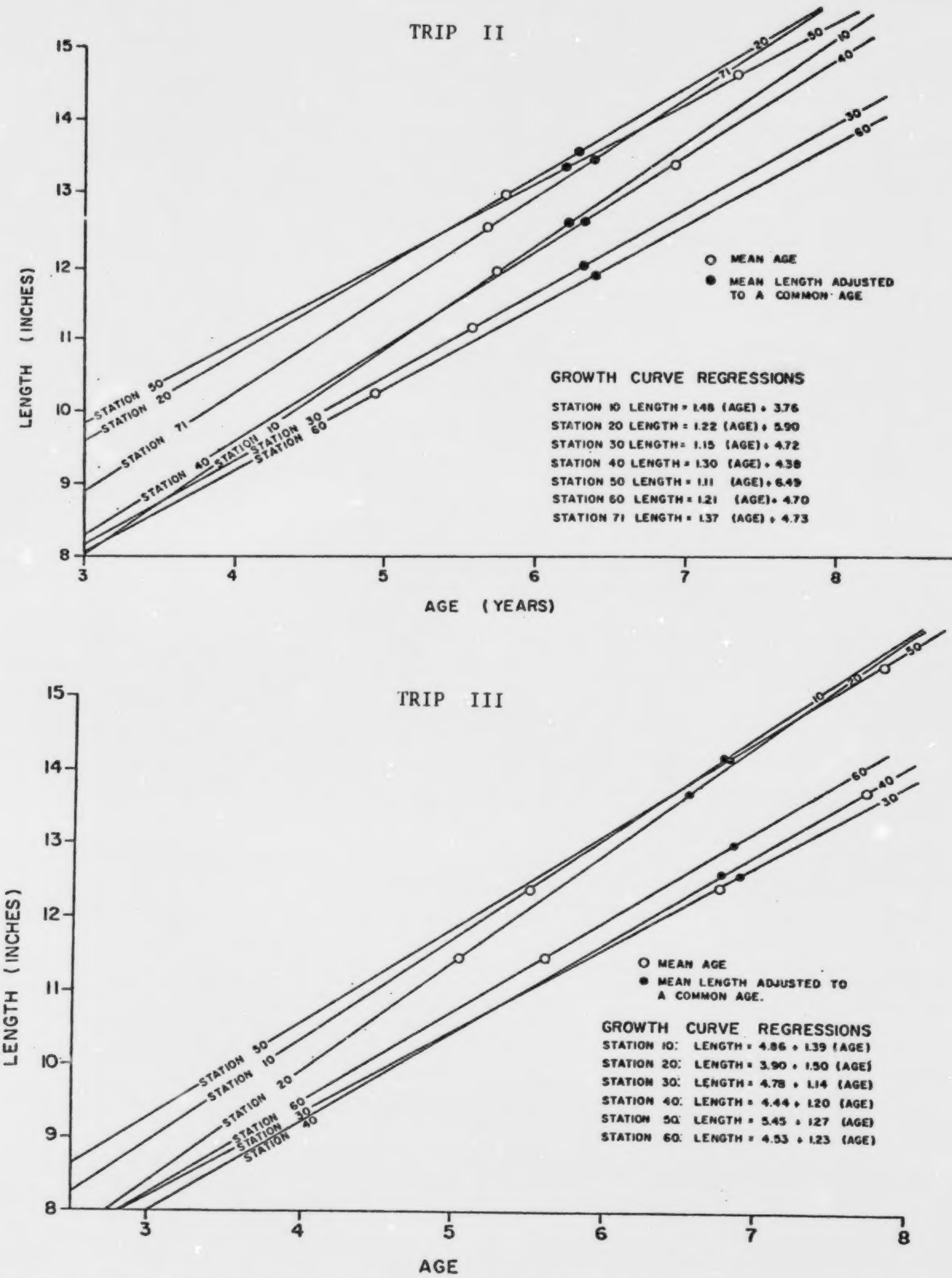


Figure 5. Comparative growth curves of whitefish during 2 trips on Southern Indian Lake, 1972.

for spawning purposes (see section 6.5.2. Length frequencies).

There was a corresponding change in mean age of fish caught in trip II and trip III in the regions. At station 20, the mean age of whitefish dropped from 5.8 years to 5.1 years while those caught at station 30 and 40 increased from 5.6 to 6.8 years and from 6.9 to 7.7 years, respectively. Fish from station 10 showed only a slight decrease in age from 5.7 to 5.5 years. The older fish, of spawning age could be moving from region 1 and 2 into regions 3 and 4. Whitefish from station 50 also increased in mean age between trip II and III (from 7.3 to 7.8), the mean ages being significantly higher than from any stations except 40.

The analyses of variance completed on the lengths of whitefish sampled in trip II and III indicate that fish from station 50 were significantly longer than whitefish from any of the other stations during this period of the summer. During trip II whitefish from station 20 and 40 were significantly longer than those from stations 30 and 60. During trip III whitefish from station 20 were significantly shorter than those from 40 and 50 and not significantly different than those from stations 10, 30 and 60. A change, then, appears to have taken place in whitefish caught in station 20 relative to those in other regions. Table 7 gives the mean lengths of fish taken at each of the main stations during trip II and trip III. There was an increase in mean length of whitefish at all stations, except station 20.

Growth rates and position of the Y-intercept of the growth curve for Southern Indian Lake and for other lakes in Northern Canada are listed in Table 8. As can be seen from the table the growth rate of whitefish from Southern Indian Lake is slower than the average for northern

Table 7. Mean lengths of whitefish from 6 stations at two different times of the summer.

	Trip II	Trip III
	(Aug. 9 - Aug. 26)	(Aug. 30 - Sept. 9)
Station Number	Mean Length (inches)	Mean Length (inches)
10	11.5	12.2
20	12.6	10.8
30	10.6	11.9
40	12.9	13.1
50	14.2	15.1
60	9.7	10.8

Canadian lakes (Carlander 1969) and in fact is slower than was found in many other lakes on the Churchill River drainage system. The Y-intercept values for Southern Indian Lake are, in most cases greater than the average and close to those given for other lakes on the Churchill River system.

6.5.4. Condition:

The 'condition' of whitefish in Southern Indian Lake (Figure 6) does not vary as greatly as does the growth rate.

Elevation of the curves from station 20 and 50 were significantly higher than those from stations 30, 40 and 71 as observed for whitefish taken during trip II, indicating that these fish (from station 20 and 50) were heavier for their length than those from the other stations. There were no significant differences in condition of whitefish collected during trip III. The differences between trip II and trip III could be the result of movement of the fish. While it is difficult to state what type of change in the population of whitefish could have occurred to produce these results, if fish are moving from a particular region towards spawning beds, it would be those fish in better 'condition' (i.e. heavier per unit length) that would be moving. Alternately, if fish in a region are in better condition in general, movement of any sized fish could create the same leveling off effect of the elevations.

McTavish (1952) found whitefish sampled from Watty Bay (station 50), to be "thin and in poor shape" "as compared with those gilled in the southern waters". This was a subjective observation that does not hold up when actual values of length and weight for these whitefish are plotted

Table 8. Growth rates (regression coefficients) and Y-intercepts of whitefish from northern Canadian lakes.

	Growth Rate (Reg. Coef) inches/year	Y-Intercept inches
Churchill River		
Southern Indian	1.25	4.83
Otter[a]	1.63	7.05
Wollaston[b]	1.29	5.16
Lac la Ronge[d]	1.31	4.30
MacKay[e]	1.37	4.59
Contact[e]	1.28	5.73
Sulphide[e]	1.05	8.28
Big Peter Pond[c]	1.38	4.96
Ile a la Crosse[c]	1.07	6.72
Nelson River		
Northern Lake Winnipeg[f]	1.35	8.03
Playgreen[f]	1.60	7.40
Kiskittogisu & Kiskitto[f]	1.20	10.50
Northern Canadian Lakes[g]	1.51	3.97

a Rawson 1960
b Rawson 1959
c Rawson 1957
d Rawson & Atton 1953
e Koshinsky 1965
f Koshinsky 1973
g Carlander 1969

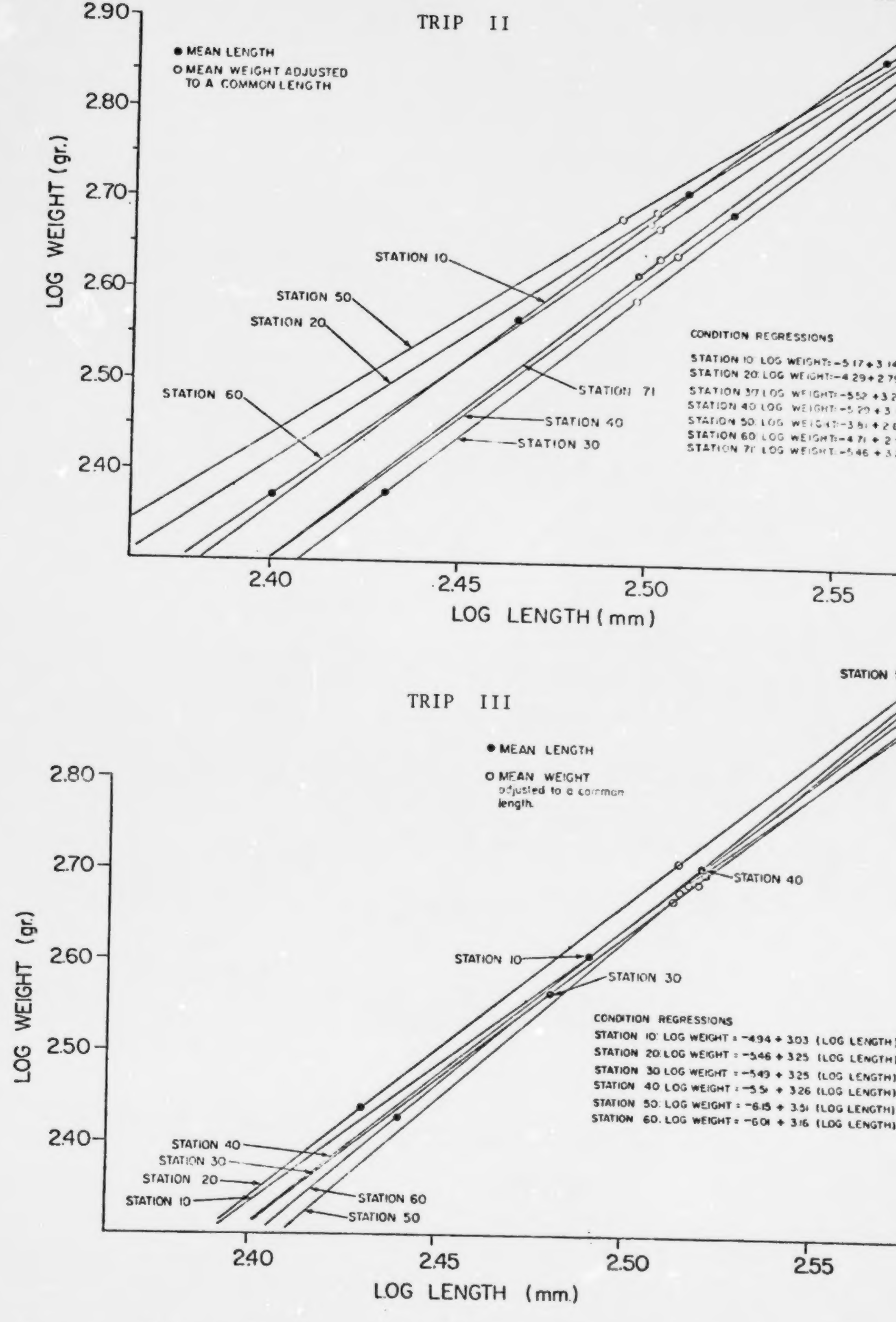


Figure 6. Comparative condition regressions of whitefish during 2 trips on Southern Indian Lake, 1972.

against the condition regression for 1952 whitefish caught in region 4 and 1972 whitefish caught in both region 4 and region 5 (Fig. 6a). Therefore, it appears that whitefish in region 5 have been and are in at least as good condition as whitefish in other regions of the lake even though this region is not under the influence of the nutrient-rich Churchill River.

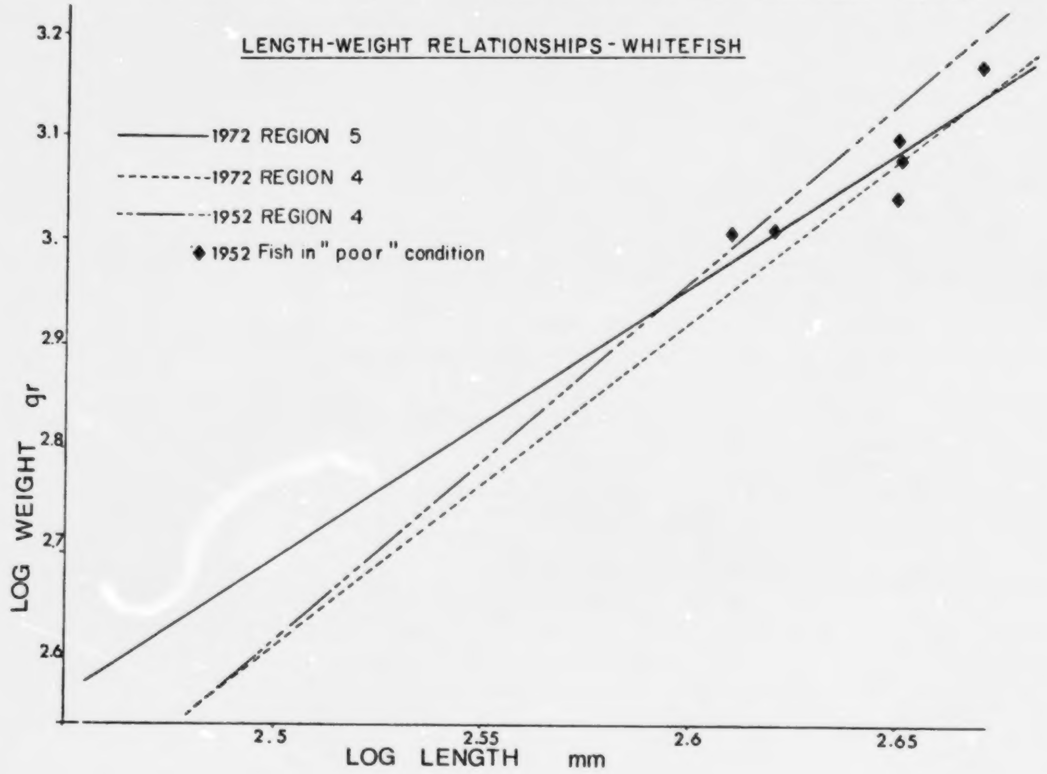


Figure 6a. Comparative condition regression of whitefish on Southern Indian Lake, 1952 and 1972.

6.5.5. Food:

Principal food items of whitefish during the summer of 1972 were amphipods (45.0% by weight) sphaeriids (21.6%), gastropods (12.8%), chironomid larvae (8.4%) as well as small numbers of mayfly nymphs (2.4%), caddis fly nymphs (5.3%), corixids (1.3%) and conchostracans (3.3%)

were also eaten.

An apparent preference for specific food becomes evident when the diet of whitefish from each region is considered (Table 9). However, preference must be tempered by availability of the food organisms. According to Hamilton (1974) Pontoporeia (amphipods) were, quantitatively, in largest supply in all regions except region 6 where the gastropods were dominant. In regions 2, 4, and 5 amphipods were the main dietary organism although only in 2 did whitefish appear to be selectively taking this item (amphipods were 68% of the diet, but only 54% of the available benthic population). In region 3 and 7 gastropods were the major organisms found in the stomachs although they comprised less than 1% of the sampled benthic population at both stations. In region 1, sphaeriids were about 5% of the sampled benthic population, but were 39% of the diet of the whitefish, although this may be indicative of a slower digestive rate for mollusca rather than an apparent preference for these organisms. From two stations chironomids were an important food item (region 1, 28% and region 4, 15%). In region 4 it was likely the large chironomids, Chironomini (subfamily Chironominae), which is present in region 4 in greater numbers than other chironomids, that was taken. Chironomini were not predominant in region 1 although likely they comprised a large percentage of the total weight of chironomids taken by whitefish at this station.

Koshinsky (1971) found amphipods to be the principal food item of whitefish in Trout and McIntosh Lake as did McPhail and Lindsey (1970) in Great Slave Lake and Lake Athabaska, and Bajkov (1930) in Lake Winnipeg.

Table 9. Food of whitefish as percent weight by items from 7 regions on Southern Indian Lake, 1972.

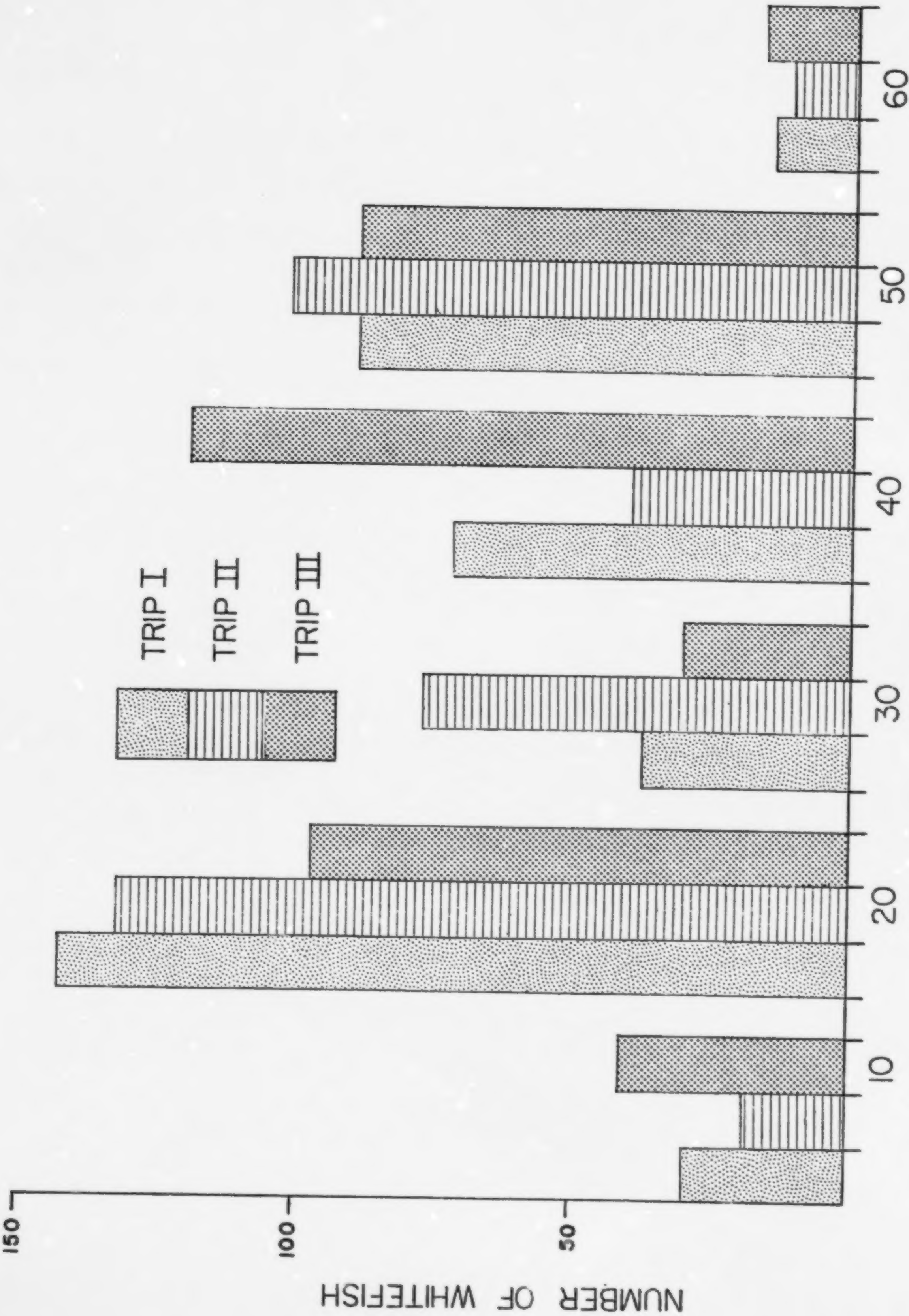
	Region						
	1	2	3	4	5	6	7
Amphipods	19.48	67.84	10.47	47.02	53.88	0.70	10.82
Sphaeriids	37.40	6.96	9.67	15.56	28.76	35.44	13.45
Gastropods	1.42	0.56	31.38	13.05	4.67	57.77	32.97
Chironomid larvae	25.65	11.70	3.92	15.36	3.77	0.02	1.60
Caddis larvae	6.49	0.44	17.68	4.73	5.93	2.48	0.33
Corixidae	1.05	0.60	10.92	1.08	0.03	0.76	6.73
Conchostraca	1.10	4.00	8.74	2.82	2.26	0.70	19.75
Mayfly nymphs	7.41	7.90	7.22	0.38	0.70	2.13	14.35
Number examined	105	197	107	383	383	79	74
% feeding	66	44	52	65	63	77	47

6.5.6. Catch per unit effort:

Numbers of whitefish caught in the experimental nets during the three trips on Southern Indian Lake have been compared between the major stations and between trips (Fig. 7). During trip I the greatest return effort was at station 20 with that from station 50 being the next. During the next two trips the catch per unit effort at station 20 progre decreased while that at 50 remained approximately the same. Also, durin trip II, the catch per unit effort at station 40 showed a decrease, foll by a marked increase (300%) during trip III. In general, it appears that the population size as estimated from catch per unit effort at stat 10, 50 and 60 remained stable, while in area 20 it decreased and in area 40 increased.

Providing the experimental nets were set in a manner that would replicate the results of the preceding trips, it appears that the popula of whitefish in region 4 during trip III had been augmented from another source. From the appearance of the data it appears possible that the ot source could have been region 2.

The average catch per unit effort for whitefish from the major stations on Southern Indian Lake in 1972 is much higher than the catch p unit effort from other lakes in northern Manitoba and Saskatchewan (Tabl Although some of the lakes listed are on the Churchill River in Saskatc the river at this location is considerably smaller than when it reaches Southern Indian Lake (approximately 1/3 the size). Only Playgreen Lake, receiving the full flow of another major river system (Nelson) displays a similar C.U.E. suggesting that in Southern Indian Lake (Churchill Rive


NUMBER OF WHITEFISH
150
100
50
10
20
30
40
50
60
TRIP I
TRIP II
TRIP III

STATIONS

Figure 7. Total number of whitefish caught in one gang of gillnets at the major stations during 3 fishing trips on Southern Indian Lake, 1972.

Table 10. Catch per unit effort (C.U.E.) for whitefish from twelve l in Northern Saskatchewan and Manitoba. All data except fr Southern Indian Lake have been changed to the standards se for the Southern Indian Lake data to allow for comparison.

Lake	C.U.E.	Lake
Southern Indian	45	Churchill[a]
Southern Indian*	56	Cree[d]
		Mountain[c]
Playgreen[b]	46	Nistowiak[c]
Lac la Ronge[a]	44	Drinking[c]
Big Peter Pond[a]	42	Otter[c]
Reindeer[a]	25	
Wollaston[d]	20	

* C.U.E. for whitefish from the main lake regions; 1, 2, 3 and 4.

a from Koshinsky 1965.

b from Ayles 1973.

c from Rawson 1960.

d from Rawson 1959.

and Playgreen Lake (Nelson River) a major river system is of importance to the productivity of the lake.

6.5.7. Implications of flooding and diversion on whitefish:

There is insufficient evidence to state that whitefish migration between region 2 and 4 is important to the whitefish population in Southern Indian Lake. However movement connected with an economically important population of whitefish (region 4) does appear to be present. Little is known about the plasticity of homing in this species but the diversion of the Churchill water away from region 4 could disrupt the migration pattern.

Flooding will submerge existing spawning beds to greater depths possibly adversely affecting the spawning success of whitefish. Increased sediment loads in the lake water resulting from the inundation of unstable shorelines could result in the "smothering" of whitefish eggs. While these effects will not immediately reduce the size of the whitefish population alarmingly there is liable to be some reduction in whitefish recruitment, at least initially, and thus lower populations in the future.

According to Hamilton (1974) the overall benthic production in Southern Indian Lake following diversion will likely be reduced by 15-30% with reductions as great as 50% occurring in regions 3 and 4. Even if this reduction does not create a "starving" effect on whitefish it could reduce the usually very fast growth rate of the young enough to lengthen the time this vulnerable stage is available to predators, and hence could increase mortality at this stage (Lindstrom 1963).

If Southern Indian Lake follows the pattern of other northern reservoirs (Crooks, 1972) it is to be expected that the whitefish population will suffer an initial decrease in recruitment. This should be followed by an increase as inundated areas release nutrients to the system, then a final stabilization somewhat lower than the present population size.

6.6. YELLOW WALLEYE

6.6.1. Back calculation

Because relatively few older walleye were caught in most regions of Southern Indian Lake, information from the back calculations is not extensive enough to suggest the presence or absence of Lee's phenomenon (Table 11). From the back calculated data the mean length of the walleye at the formation of the first annulus is approximately the same throughout the lake, and average annual increments do not vary greatly. Weagle and Baxter (1973) found that because of the warmth of the streams entering Southern Indian Lake in May spawning took place at approximately the same time everywhere.

6.6.2. Length-frequency:

The length-frequency distribution for walleye at particular stations in Southern Indian Lake (Figure 8) indicates some regional differences at particular times of the year within the lake. While the gillnettings of walleyes is dependent upon the activity of these fish, and hence dependent to some extent onthe time of the year the netting is done, difference within any one trip should be indicative of population size and structure.

During trip I few walleyes were caught in stations 10-50 relative to those caught in the remaining stations, and in these stations, except at station 50, the fish that were caught were almost all of a size too small for spawning. From stations 2, 52, 53 and 60, however, the number of walleyes caught was large, and the dominant length class was the size of spawning walleye. (According to Weagle and Baxter (1973) average size of spawning

Table 11. Back calculated fork lengths at the time of each annulus formation for each age group of walleye from 6 different stations on Southern Indian Lake. Average fork lengths and annual increments for all age groups are included.

AGE AT CAPTURE	NO. OF FISH	FORK LENGTH (INCHES) AT ANNULUS FORMATION						
		1	2	3	4	5	6	7
Station 10								
4 +	6	5.2	7.4	9.9	11.7			
5 +	11	5.2	7.2	9.2	11	12.5		
6 +	8	4.4	6.3	7.8	9.3	10.9	12.5	
7 +	3	5.1	7.1	9.3	10.9	12.7	14.1	15.5
		5.0	6.9	9.1	10.7	12.0	13.3	15.5
		5.0	1.9	2.2	1.8	1.3	1.3	1.3
Station 20								
3 +	2	5.6	8.2	10.5				
4 +	7	4.5	6.9	8.8	10.9			
5 +	9	4.6	6.6	8.5	10.1	11.8		
		4.9	7.2	9.3	10.5	11.8		
		4.9	2.3	2.1	1.2	1.3		
Station 30								
2 +	4	6.1	9.0					
3 +	8	4.4	6.9	9.2				
4 +	11	4.3	6.3	8.2	9.9			
5 +	7	5.1	6.8	8.2	9.7	11.1		
6 +	3	4.8	6.5	8.3	10.0	11.5	12.8	
		6.9	7.1	8.5	9.9	11.3	12.8	
		4.9	2.2	1.4	1.4	1.4	1.5	
Station 40								
2 +	3	4.8	7.7					
3 +	4	4.9	7.3	9.2				
4 +	4	4.7	6.8	8.8	10.8			
5 +	1	5.1	7.3	8.8	10.0	11.3		
		4.9	7.3	8.9	10.4	11.3		
		4.9	2.4	1.6	1.5	0.9		
Station 50								
3 +	6	6.1	8.8	11.0				
4 +	16	4.6	6.8	9.0	11.0			
5 +	21	4.8	7.1	9.3	11.5	13.3		
6 +	4	5.8	8.1	10.4	12.3	14.1	15.7	
7 +	3	3.9	6.0	7.9	9.7	11.7	13.5	15.5
		5.0	7.4	9.5	11.1	13.0	14.6	15.5
		5.0	2.4	2.1	1.6	1.9	1.6	0.9
Station 60								
3 +	2	4.2	6.7	9.4				
4 +	12	5.2	7.4	9.8	11.8			
5 +	15	4.9	7.2	9.2	11.1	12.8		
6 +	7	4.4	6.1	7.9	9.6	11.1	12.5	
7 +	4	4.8	7.5	9.6	10.7	13.7	15.1	16.4
		4.7	7.0	9.2	10.8	12.5	13.8	16.4
		4.7	2.3	2,2	1.6	1.7	1.3	2.6

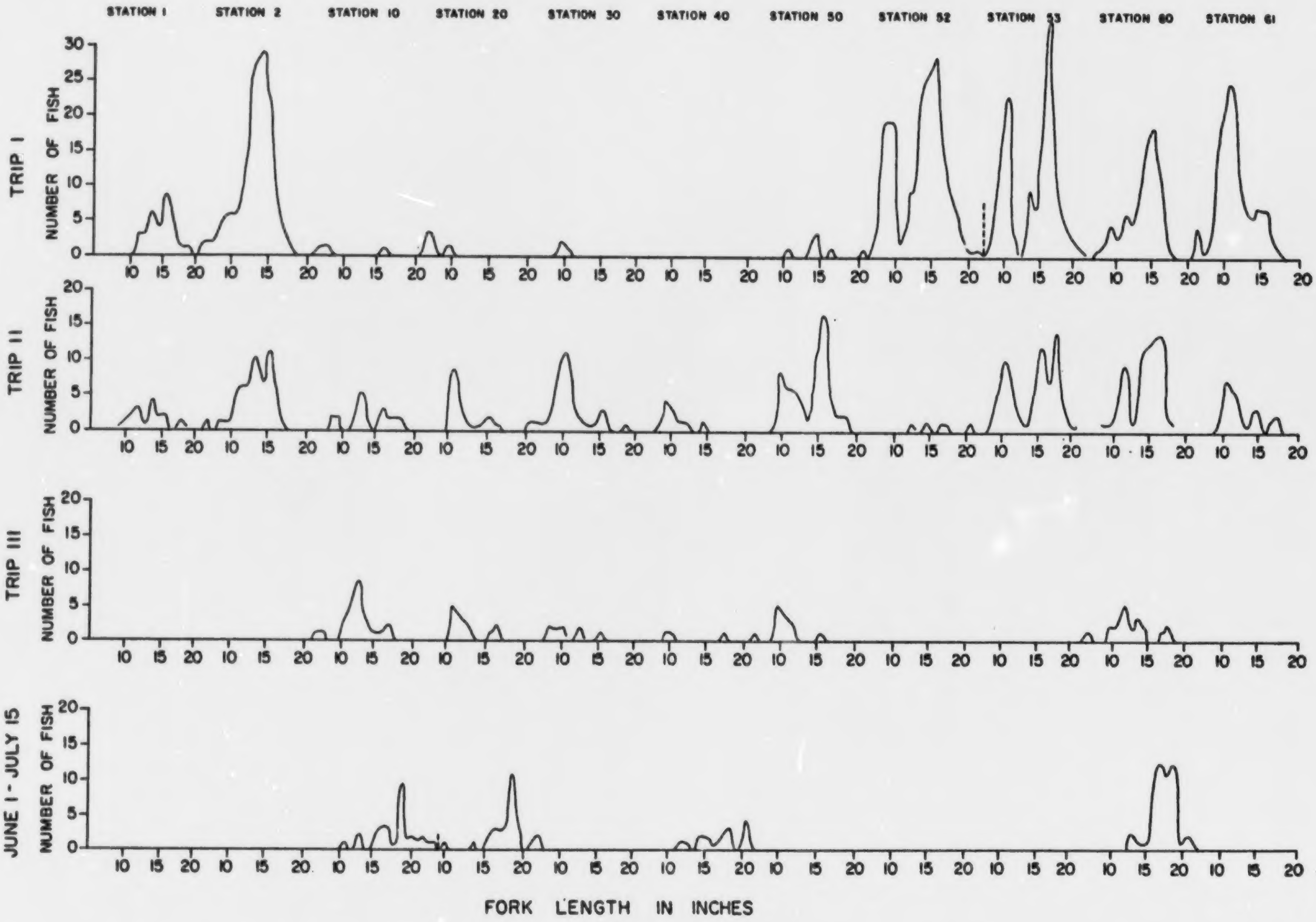


Figure 8. Length-frequency composition of walleye in Southern Indian Lake, 1972 and 1952.

walleye is approximately 14.2 inches). There was also a relatively large catch of walleye from station 61 although the dominant length class, 11.5 inches, is probably too small to consist of significant numbers of spawning walleye.

The walleye caught in stations 2, 52, 53 and 60 were probably remaining concentrations of the spawning populations that move to the Barrington, Muskwesi, Waddi Rivers and streams in the South Bay, respectively. While these were captured well after the time of spawning (July 1 - July 17), there is evidence to suggest that after spawning in these streams walleye move further upstream, not returning to the lake until early July (Weagle, pers comm). Rawson's (1956) work supports this and suggests walleye may remain upstream from 3 to 6 weeks after spawning. Figure 8a, showing the walleye length-frequency curve for station 2 on July 7, 1972 and for the Barrington River on May 27, 1973, shows the similarity in the shape of the curve at these two times. The data from the Barrington consists of fish selected specifically for spawning information which could explain the shift to the right for these data.

The major peak at station 61 as well as the minor peaks at station 52 and 53, all approximately at the 10 inch size suggest the presence of a second dominant size class in the lake which is present with the older walleye.

During trip II there was a more equal representation of walleye in all stations, suggesting a movement back into all areas from spawning grounds. Depending on the location of the station, the dominant length class in trip II and trip III was either about 10 inches or about 15 inches (with the exception of station 10 where the dominant length class was about 12.5 inches).

In most cases, it was those stations that had what appeared to be the

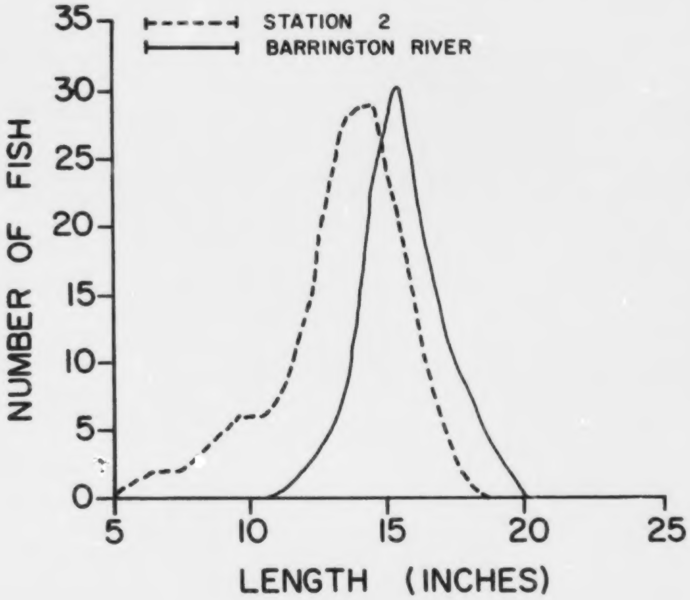


Figure 8a. For explanation, see text.

spawning sized walleye in trip I that maintained the dominant length class at 15 inches, and those that did not that recorded the strength in the 10 inch length class. The major exceptions to this appeared at station 50 and 52. During trip II the walleye population decreased in size at station 52 (see also Catch per unit effort Section 6.5.6.) and in trip III, no walleye were caught there. There was an increase in relative number of fish at station 50 during trip II with a very dominant length class at about 15 inches. In trip III the relative number of fish was maintained but the dominant 15 inch class had disappeared. Since the number of fish caught that were about 10 inches long did not change appreciably between trip II and trip III, it is unlikely that the decrease in larger fish was caused by a change in catch per unit effort. Furthermore, the dominant age class was 5 years at trips II and III but the mean length for the five year olds changed from 15.6 inches to 11.1 inches. There is no apparent explanation for this marked reduction in number of only larger sized fish of an age class.

The dominant length class of walleye from stations 10, 20, 40 and 60 (Figure 8) in 1952 (McTavish) was always greater than 15 inches, and usually greater than 17 inches. In a comparison of mean lengths and weights of walleye caught in the 2 3/4" mesh in 1952 and 1972 (Table 12), only at station 10 were fish from the 1972 catch larger and at all other stations the 1972 mean was much smaller. The apparent general decrease in the weights and lengths of walleye since 1952 probably can be attributed to the effects of the commercial fishery, as was the change in the mean weights and lengths of whitefish (Section 6.5.2). No walleye were caught in the commercial sized experimental gillnet (5 1/4") during trip II of the 1972 collection. This is not unexpected, nor a reflection of over-exploitation by the commercial fishery. Large walleye are difficult to catch, both experimentally, and commercially during mid-summer.

6.6.3. Growth rate:

There were definite differences in the age-length regressions calculated for those samples taken during trip II that were aged that were not noticeable in those samples taken during trip III.

The rate of growth of walleye as observed during trip II was

Table 12. A comparison of mean lengths and weights of walleye caught in the 2 3/4 inch mesh in 1952 and 1972 from Southern Indian Lake.

	Station 10		Station 20		Station 40		Station 60	
Year (Number of fish)	1952[a] (3)	1972 (3)	1952[a] (22)	1972 (3)	1952[a] (11)	1972 (3)	1952[a] (22)	1972 (17)
Mean weight (pounds)	0.8	1.5	2.4	0.7	1.8	0.9	2.0	1.5
Mean length (inches)	12.3	15.1	18.0	11.9	15.9	12.8	17.5	14.8

[a] from McTavish (1952)

significantly greater at stations 50, and 53 than at stations 60, 72 and 72A but not greater than growth of walleye taken elsewhere in the lake (Table 13). The elevations of the regression curves of data from 50, 51, 53, 60, 72 and 72A are all greater, significantly, than those from the main lake stations (10, 20, 30 and 40). It appears then that walleye caught in the north end of the lake (50, 51 and 53) were from a distinct population and were growing at a faster rate; a rate great enough to create a significantly high elevation of the regression line as well. Fish from stations 60, 72 and 72A did not appear to have the same high rate of growth, but for their age, they were significantly longer (elevation) suggesting an increased growth rate had occurred at some time, probably in early years of growth.

Mean age of walleye sampled during trip II was greater at stations 53, 60, 72 and 72A than mean age of walleye from other stations.

In almost all cases, the regions discussed in this section as having distinct populations of walleye are regions that were shown to have residual populations of spawning walleye during trip I (see section 6.6.2. walleye length-frequency). Although experimental netting did not take place in region 7 during trip I, other investigations in region 7 in 1973 indicate a large population of mature walleye at the time of spawning (Weagle and Baxter, 1973). There is evidence that, following return from the spawning area, walleye show an early summer concentration, particularly inshore, followed by a wide dispersal in August and September (Rawson 1956; Crowe 1962). These sub-populations of walleye, then, are significantly different from walleye elsewhere in the lake because of the lingering effect of the concentrati

Table 13. Summary of statistical comparisons of growth rate and elevations of growth curves for walleye from nine locations in Southern Indian Lake. Where differences between pairs were found to be significant, the number of the station with the higher value is given (growth rate, above oblique line; elevation, below oblique line). If no significant difference was found, a (-) is given.

	72A	72	60	53	51	50	40
20	-/-	-/-	-/-	-/53	-/-	-/50	-/-
30	-/72A	-/72	-/30	-/53	-/-	-/50	-/-
40	-/-	-/72	-/60	-/53	-/-	-/50	
50	50/-	50/-	50/-	-/-	-/50		
51	51/-	51/72	51/60	-/53			
53	53/53	53/53	53/53				
60	-/-	-/-					
72	-/-						

Table 14. Summary of statistical comparisons of slopes of condition regressions for walleye from nine locations in Southern Indian Lake. Where differences between pairs were found to be significant, the number of the station with the higher value is given. If no significant difference was found a (-) is given.

	72A	72	60	53	51	50	40
20	-	-	-	-	-	-	-
30	-	-	-	53	-	-	-
40	-	-	40	-	-	-	
50	-	-	50	-	50		
51	-	-	-	-			
53	-	53	53				
60	-	-					
72	-						

of the older fish in the area. By trip III (August 30 - September 9) growth rates of walleye were not significantly different at any of th major stations, suggesting that the distinct sub-populations of walle present in trip II had dispersed.

6.6.4. Condition and mean length:

The regression lines of length against weight for walleye taken trip II and trip III show little differences between data from each o regions suggesting a uniformity of condition for walleye throughout t lake (Table 14).

However, a significant difference did exist between the mean le of walleye taken during trip II as calculated by an analyses of varia Walleye from stations 50, 51, 53, 60, 72 and 72A were all significant longer than walleye from the other major stations of the lake. This corresponds to the difference found in the growth analyses (section 6 and again, is probably indicative of concentrations of mature walleye remaining in particular areas within the lake. By trip III there wer significant differences between lengths of walleye taken at the sampl stations which supports the suggestion that the mature stocks were mo uniformly dispersed.

6.6.5. Food:

Walleye fed almost exclusively on fish with cisco and/or whitef being predominant (Table 15). Trout-perch, usually considered to be important forage fish for walleye (McPhail and Lindsey, 1970), were n found in any of the stomachs sampled. Mayfly nymphs and caddis nymph were identifiable but only in very small quantities.

This predominance of fish on the diets of walleye in Southern India Lake is much different from that found for walleye in other Churchill Riv lakes (Trout Lake, Koshinsky 1971; Otter Lake, etc., Rawson, 1960) where invertebrates were much more important. Koshinsky (1971) does say, howev that a fish diet is probably more typical of walleye from large Shield la

Table 15. Food of walleye as percent weight by items in seven regions Southern Indian Lake, 1972.

	Region						
	-	1	2-3	4	5	6	7
Cisco	-	35.2	59.1	-	36.6	57.9	41.7
Cisco and/or whitefish	56.5	47.2	27.4	33.3	44.4	13.4	34.7
Perch	21.3	-	-	-	-	-	-
Ninespine stickleback	-	-	2.1	-	1.4	-	1.3
Sculpin	-	-	2.3	11.0	1.2	-	1.4
Unidentified fish remains	22.2	17.6	9.1	41.9	14.6	28.7	18.2
	-	-	-	13.8	-	-	2.7
Caddis larvae	-	-	-	13.8	-	-	2.7
Mayfly nymphs	-	-	-	-	1.8	-	-
no fish sampled	23	42	61	33	179	126	75
% feeding	52	52	28	55	35	56	29

6.6.6. Catch per unit effort:

Catch per unit effort for walleye changed among trips and among stations following the same pattern as was determined from the length frequency and growth rate analyses. During trip I, at about the time t walleye would be returning from the streams, the values for catch per u effort (C.U.E.) were high in those stations (Table 16: Stations 02, 52 53, 60 and 61) that were at the mouths of spawning streams. During tri the C.U.E. decreased at these stations and increased at the other stati in the lake until during trip III the C.U.E. was similar at all station sampled.

6.6.7. Implications of flooding and diversion on walleye:

Changes made to the particular spawning sites, usually streams, the raising of the water level, as well as changes in water movement wi the lake that could change the methods for homing could effectively red the number of successful spawners enough to harm the size of the walley population in Southern Indian Lake. Changes in water flow in streams b raising the water level would increase sedimentation rates on the existi spawning grounds which would have an adverse affect on incubating eggs. However, it is likely that adequate spawning grounds will be established at higher positions on the streams that will not be directly affected by flooding. Incubating eggs of shore-spawning walleyes could also be affected by increased sedimentation rates within the main lake. It is evident from research completed on walleye elsewhere (Crowe 1962; Eschme and Crowe 1955; Rawson 1956) that walleye have a tendency to "home" to

Table 16. Total catch of walleye, in numbers, from one gang of nets set at different stations during three trips from Southern Indian Lake, 1972.

	Stations												
	01	02	10	20	30	40	50	51	52	53	60	61	62
Trip I	13	86	2	6	2	0	4	1	103	157	40	58	19
Trip II	11	52	12	10	23	6	37	16	18	87	40	15	8
Trip III	NF	NF	13	10	6	2	9	NF	NF	NF	12	NF	5

NF - not fished

particular spawning sites. Migration for the purpose of spawning can involve distances as great as 175 miles (Eschmeyer and Crowe, 1955) so that walleye could be moving from any part of Southern Indian Lake to a particular stream to spawn. Diversion of the Churchill River from a large area of Southern Indian Lake could prevent mature walleye from returning to their spawning grounds.

According to Patalas (1974) and Hamilton (1974) there could be a significant decrease in the productivity of both plankton and benthic organisms following diversion, particularly in regions 3 and 4. A decrease in these food items will likely have a direct (adverse) affect on young walleye, and an indirect (again adverse) affect on adult walleye.

6.7. NORTHERN PIKE

6.7.1. Length-frequency:

The length-frequency curves prepared for pike (Figure 9) show essential similarity in numbers of pike at specific lengths among stations and trips. The dominant length-class in almost all situations is approximately 20 inches and according to the aging data this is representative of pike aged 5 years.

During trip I there were concentrations of longer (hence older) pike at such stations as 02, 30 and 50 which decreased by trip II. These concentrations were likely post-spawning pike prior to their dispersion to other parts of the lake.

Mean weight and mean length of pike have decreased since 1952 (McTavish 1952) (Table 17). As well, McTavish captured pike in the 5 1/4" mesh, while there were no pike taken in the 5 1/4" mesh in 1972. Such a decrease in mean sizes could normally be attributed to exploitation of a species by a commercial fishery, however, northern pike on Southern Indian has never been considered to be a commercially desirable fish. Incidental catches of northern pike in the commercial and domestic gillnets could account for some pressure on this species.

6.7.2. Growth rate and age:

There were no significant differences between major stations in growth rates and elevations of growth curves (age-length) for pike taken during trip II, with the exception of station 10. Pike taken from station

10 were unusually small; for example the mean at age 3 was 7.6 inches at station 10 and 20 inches at station 20 ., yet these small fish did not appear in the catches taken from station 10 in trip III. Either the pike taken at station 10 during trip II were from an unusually stunted population, or the sample taken, though supposedly random, was not truly representative of the population at station 10. The mean ages of pike at all the stations during this trip were the same also, with the exception of pike taken from station 72A which were significantly older pike than taken anywhere else in the lake at this time.

Pike taken from station 30 during trip III had a faster growth rate than pike from other stations though the intercept on the Y-axis is uncharacteristically low.

Except for the pike from station 40, which were significantly longer, the mean length of pike at a common age was not different between stations.

Pike from station 60 were significantly younger and shorter than those from other regions of the lake during trip III, and from those taken from station 60 in trip II. There does not appear to be an obvious explanation for this shift in age-class in the South Bay.

6.7.3. Condition:

Northern pike from Southern Indian Lake are not as in good condition, in general, with a length-weight relationship of

$$\text{Log weight} = 6.71 + 2.6 \text{ (log length)}$$

as those from Lake of the Woods (Carlander 1969)

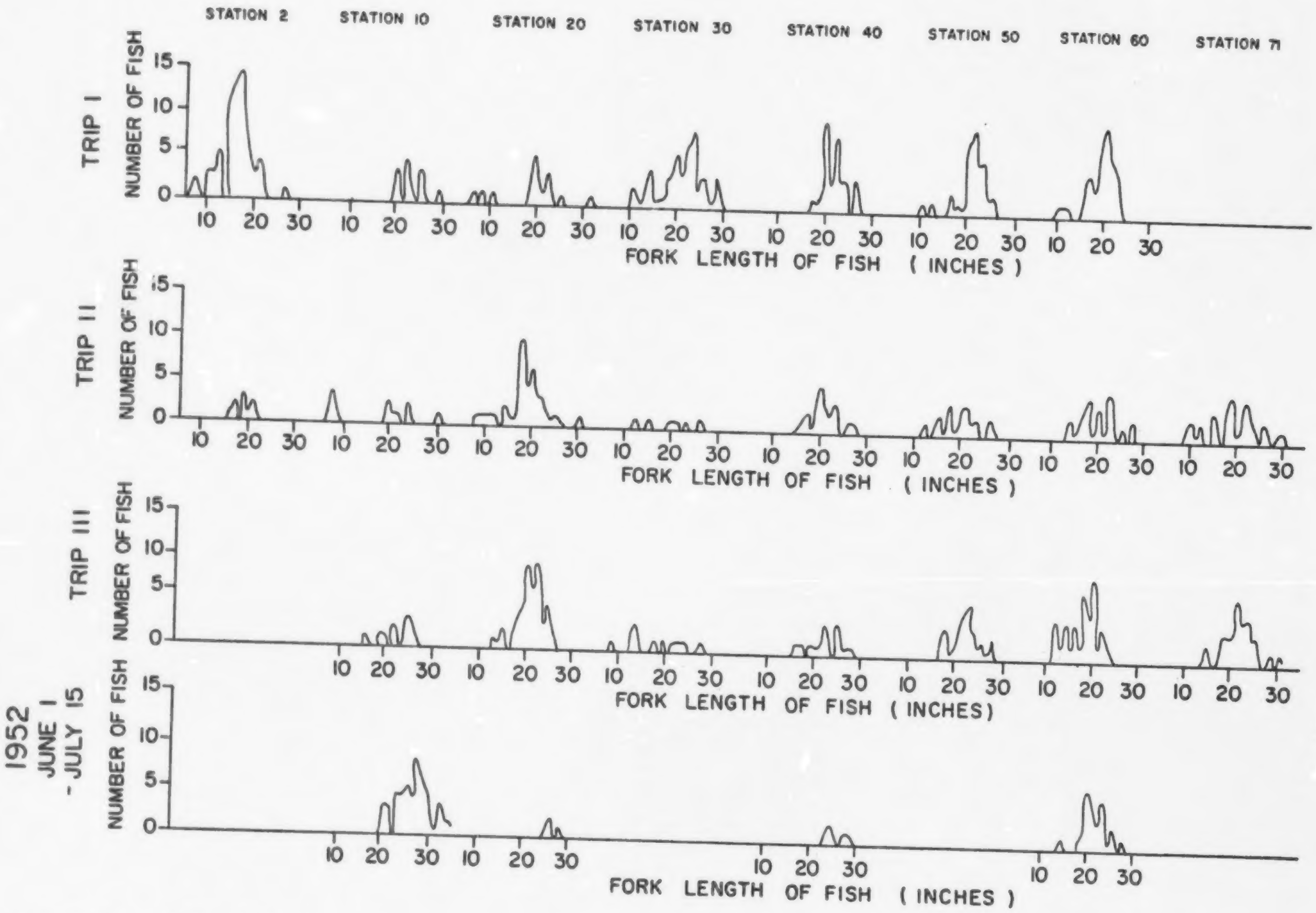


Figure 9. Length-frequency composition of northern pike in Southern Indian Lake, 1972 and 1952.

Table 17. Mean weight and mean length of northern pike taken in a 2 3/4" mesh gillnet from Southern Indian Lake. The numbers in brackets are the number of fish used to derive the means.

	Station 10		Station 40		Station 60	
Year (Number of fish)	1952* (13)	1972 (3)	1952* (7)	1972 (6)	1952* (10)	1972 (17)
Mean weight (pounds)	6	2.2	4.8	2.9	3.1	2.1
Mean length (inches)	27.6	21.5	27.3	22.6	23.7	20.5

* from McTavish (1952)

$$\text{Log weight} = 6.2 + 3.1\ (\text{log length})$$

and from Lac la Ronge (Koshinsky 1972)

$$\text{Log weight} = -5.4 + 3.1\ (\text{log length})$$

Within the lake, differences between stations and between trips become apparent. During trip II, the pike from different stations were similar in length and weight. The sample taken during trip III indicates, however, that although the weight per unit length of pike as observed from station 30 increases at a faster rate than does weight per unit length of pike observed elsewhere, for a common length they are not as heavy as pike from other parts of the lake. This could suggest that pike observed from this station are not in as good condition, at this time of year, although it seems unlikely that a significant change could occur between trips II and III.

Pike observed from station 60 during trip III had a significantly smaller mean length than pike observed from the same station during trip II and from other stations also during trip II. A significant difference suggests a population (or sub-population) of pike different from the main lake population. Yet this difference did not appear during trip II. It is possible that during the time that trip II was in progress post-spawning dispersal was still taking place and it was not until the time of trip III that the resident populations had reformed. This would explain the variations between trip II and III in both growth rate and condition.

Extensive migration of pike has not been found in lake conditions, however Hill suggests that in a river situation migration of pike may be more prevalent (Koshinsky 1972). Though Southern Indian is considered to be a lake, many riverine conditions are maintained by the strong flow of the Churchill River through it and hence extensive migration of pike could well exist.

6.7.4. Food:

Fish were found in all pike stomachs that contained food, with cisco and/or whitefish usually predominating (Table 18). Pike also fed extensively on white sucker in regions 1 and 5, and on burbot in regions 6 and 7. There is some evidence for selectivity since, with the exception of white sucker in region 1, these food sources were scarce in the experimental gillnets set in these regions.

Table 18. Food of northern pike as percent weight by items in 7 regions of Southern Indian Lake, 1972.

	Regions						
	0	1	2-3	4	5	6	7
Cisco	-	22.0	26.6	22.4	42.4	25.3	24.6
Cisco and/or whitefish	-	8.7	26.6	2.8	3.4	7.6	35.8
Whitefish	-	-	32.8	32.8	15.8	25.4	-
White sucker	-	60.4	3.2	15.6	23.7	5.4	1.3
Burbot	-	-	-	-	-	31.3	26.6
Walleye	-	-	-	-	6.4	-	-
Perch	10.9	-	-	-	-	1.2	1.4
Trout-perch	-	3.4	7.5	10.6	1.4	-	-
Ninespine stickleback	-	-	-	-	-	1.2	-
Sculpin	-	-	-	2.5	1.4	-	-
Unidentified remains	-	5.5	13.6	13.2	5.5	2.6	5.3
Crayfish	86.4	-	-	-	-	-	5.0
Mayfly nymphs	2.7	-	-	-	-	-	-
No fish examined	15	39	167	148	136	134	118
% feeding	33	38	43	41	36	39	35

6.7.5. Catch per unit effort:

The catch per unit effort (C.U.E.) of northern pike at each of the main stations in the lake changed markedly throughout the summer except at station 40 as can be seen in the following C.U.E.'s:

Station	10	20	30	40	50	60
Trip I	9	11	31	10	25	26
Trip II	4	25	4	13	14	15
Trip III	5	30	7	11	22	30

Although evidence from the literature (Koshinsky 1972) suggests that northern pike movement in a lake situation is limited (typically less than 2 miles), this may not apply to more riverine situations such as Southern Indian Lake. From the data it appears that there is a decrease in the early concentration of northern pike in region 3 and region 1 between trip I and II, and this concentration remains low through trip III. Coincidentally, the catch per unit effort in region 2 continued to increase between trips. Northern pike have been observed to remain in spawning areas anywhere up to 90 days before returning to the lake (Carbine 1942) and it may be that fish in region 1 and 3 during trip I may have subsequently dispersed, or possibly moved into region 2.

Koshinsky (1972) suggested that young pike in Lac la Ronge showed a greater preference for shallow water than did the larger fish and that there was no evidence that the pike sought the cooler deep water during the summer months. Data from Southern Indian Lake (Table 19) show that during trip II a relatively greater number of pike could be found at deeper depths at stations 10, 20 and 30 but in general the length of the pike at the deeper depths was not greater. Probably, because the water at the greater depths in Southern Indian is not appreciably cooler the observations at stations 10, 20 and 30 were simply indicative of a general dispersion of pike as the summer progressed and not the seeking of any specific preferred condition

6.7.6. Implications of flooding and diversion on northern pike:

Northern pike can be expected to respond positively, at least initiall to the new impoundment. Crooks (1972) found that following inundation of Lac Seul the commercial catch (in weight) of northern pike increased more than 4 times in 18 years. Although increased turbidity could adversely effect incubating northern pike eggs in the lake it is unlikely the effect will be widespread. In general, the newly inundated land will provide ideal pike habitat. New areas of submerged vegetation will increase available spawning areas. Flooding of uncleared land will increase the nutrient supply to parts of the lake with an end result of an increase in supply of some sources of food such as white sucker, perch and zooplankton (for fry). At the same time the new impoundment could adversely affect the growth of other sources of food (see whitefish 6.5.7) thus increasing the length of time they are available as prey to pike.

Increased growth, condition and availability of this species

Table 19. Number and mean lengths (inches) of northern pike caught in a gang of gillnets in shallow and deep sets at three different times of the summer season from Southern Indian Lake, 1972.

Stations	Trip I				Trip II				Trip III			
	Shallow		Deep		Shallow		Deep		Shallow		Deep	
	No	Mean Length	No	Mean Length	No	Mean Length	No	Mean Length	No	Mean Length	No	Mean Length
10	10	23.1	3	26.2	2	21.3	5	23.6	5	20.8	4	24.2
20	7	15.9	11	21.2	2	24.9	40	19.2	31	21.5	18	22.2
30	46	21.4	8	25.2	2	22.8	4	19.3	3	17.1	8	17.4
40	39	22.5	0	-	17	21.1	5	23.4	15	24.3	2	23.1
50	23	21.7	17	21.5	23	20.7	1	27.4	29	23.3	4	23.2
60	32	19.8	17	20.3	11	20.5	14	20.4	31	17.1	17	20.9

following impoundment should provide much more attractive northern pike both for sport and commercial fishing for a number of years. However, if the pattern is the same as shown for Lac Seul (Crooks, 1972) the fin northern pike fishery will drop to less than the potential prior to impoundment.

6.8. LAKE CISCO

There is some confusion among fisheries investigators about the species group with the common names "cisco" and "tullibee". Bajkov (193
discusses several (probably 3) species all of which were called "tullibe
and were given a total of 6 different descriptive names by commercial fishermen. He felt that as well as the obvious meristic differences (e.
gill raker counts) there were differences in feeding habits and growth rates. Carlander (1969) differentiates between cisco and tullibee by defining tullibee as "herring of smaller lakes usually deeper bodied".
is able to show differences in condition and growth between the two type
though he never defines them specifically. McPhail and Lindsey (1970) admit that there is a high degree of variability between ciscoes which m
or may not be strictly phenotypic. They discuss ciscoes under the speci
name of the "Coregonus artedii complex" though they do suggest the possibility of the presence of a second species C. sardinella in some locations.

With these inconsistencies in mind, no attempt has been made to differentiate species of Coregonus within the lake although the possibil
exists that there is more than one species (e.g. from region 7, three le
of maturity were found in ciscoes of the same size (J. Sigurdson, pers. comm.)). For this discussion it is assumed that, exclusively, Coregonus artedii was taken from Southern Indian Lake, and that its common name is lake cisco.

6.8.1. Length-frequency and catch per unit effort:

Movement of ciscoes during the summer months has been well documented. Fry (1937) was able to show the presence of both horizont and vertical movement of ciscoes in Lake Nipissing although horizontal movement was related to vertical migrations which, in turn, appeared t governed by the temperature of the surface waters. Temperatures of 20 were the upper limit for ciscoes. In Southern Indian Lake the surface temperature of water never reached 20°C and there was no evidence from catch per unit effort data to suggest that vertical migration during s months occurred in anything but a random or short-term fashion.

Length-frequency curves for ciscoes for the different stations trips (Figure 10) show very strong length class predominance existing several of the stations. Stations in region 7, particularly, had a preponderance of 5 to 7 inch fish, probably 2 and 3 years old. At sta 72A a second peak of longer fish probably 7-9 years old, was present. Observations made at stations in region 5 also showed the stronger, yo peak, both during trip II and trip III. The other major stations had more even distribution of length classes though between trips there is evidence for movements between stations.

Ciscoes in Lake Nipissing spawned at age 3 (Fry 1937) and in Ma lakes, according to Bajkov (1930) ciscoes were at least 4 years before spawning and the sexes could be differentiated only with a microscope, age 3 years. Ciscoes from Southern Indian Lake appeared to be reachin maturity by age 3 years and were probably spawning by 4 years. Increa catch per unit effort (Table 20) and an increase in 4 year-old and old

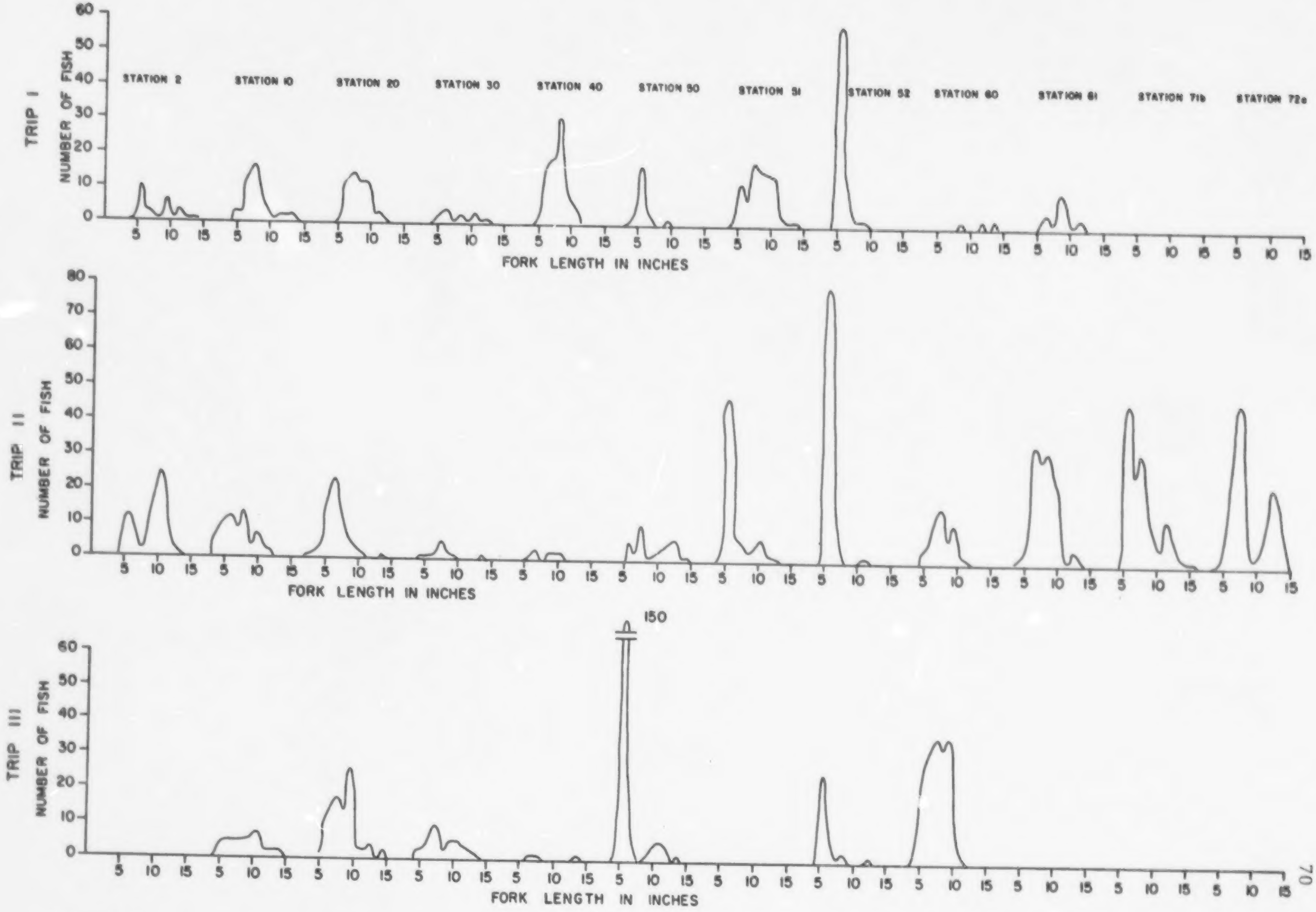


Figure 10. Length-frequency composition of cisco during 3 trips on Southern Indian Lake, 1972.

Table 20. Catch per unit effort of ciscoes from 9 stations during three trips on Southern Indian Lake, 1972.

	Stations								
	02	10	20	30	40	50	51	52	60
Trip I	18	39	35	9	23	16	55	46	2
Trip II	107	36	42	7	6	21	43	307	31
Trip III	-	22	58	25	2	114	-	26	112

- not sampled

ciscoes at stations 20 and 60 as the autumn time of spawning neared suggests a movement of ciscoes into spawning areas.

6.8.2. Age determination and growth rate:

There is little difference in either rate of growth or elevation of growth curves of cisco from different sampling stations. Ciscoes taken from station 72A were significantly larger than ciscoes from several of the other stations (Table 21), but the significant difference was not great. There were, however, definite differences in mean age between these stations. Ciscoes taken from region 7, including station 71, were significantly older than ciscoes elsewhere in Southern Indian Lake.

During trip III, there appeared to be no significant differences in growth rates, size, or mean ages of ciscoes but ciscoes from region 7 were not sampled. The suggestion, from the trip II results, that there is a difference in size between region 7 and elsewhere in the lake suggests the presence of either a different sub-population of ciscoes, a different species of cisco, or different conditions in region 7 that effect a specific portion of the total lake's population of ciscoes. Either of the latter two could be the correct assumption.

In comparing present growth curves with those prepared from data in Carlander (1969) for Canadian ciscoes (as opposed to tullibee) it appears that the Southern Indian Lake ciscoes are of a smaller size but have a greater growth rate than "Canadian" ciscoes. This suggests that early growth, not appearing on the growth curve, is typically much greater for "Canadian" ciscoes than for those from Southern Indian Lake.

Table 21. Statistical comparisons of length-at-age and mean age between the larger and older cisco at stations in region 7 and stations in the main lake. Numerical values given are "t" values. A value greater than 1.96 is significant and the larger the value, the greater the significance. Values are reported in terms of region 7 versus the main lake stations.

Length at Age

	Station			
Region	10	20	30	40
72A	2.1	2.2	NSD	2.4

Mean Age

	Station				
Region 7	10	20	30	50	60
71A	3.5	3.9	NSD	NSD	3.6
72	3.5	4.1	NSD	NSD	3.7
72A	5.3	5.8	2.6	2.8	5.5
72B	3.1	3.6	NSD	NSD	3.5

NSD - no significant difference

6.8.3. Condition:

There was little difference in the condition of ciscoes among stations and among trips in Southern Indian Lake. In general ciscoes observed during trip III were heavier for their length than ciscoes observed during earlier trips, but these differences were not great enough to be statistically significant.

As was the case in growth rate of cisco (section 6.8.2) mean lengths of cisco do differ between region 7 and the rest of the lake during trip II.

The condition formula for ciscoes for Southern Indian Lake ($\log W = -6.8 + 3.18\ [\log F.L.]$) lies about mid-way in the list of formulae for ciscoes from different lakes listed by Carlander (1969) and it does reach the level that Carlander considers typical of "tullibee" ($\log W = -5.06 + 3.17\ [\log S.L.]$). It appears from this data that although Southern Indian Lake cisco have a faster growth rate than do "Canadian cisco" (see growth rate section 6.8.2) the condition of these fish, in general make them equal to the standards as set by Carlander defining tullibee.

6.8.4. Food:

The total diet of ciscoes was more varied than that of whitefish and there were greater regional differences as well. Overall the crustacean Mysis relicta was consumed in greatest quantities (26% by weight) though mayfly nymphs were a close second at 24% and unidentified fish remains accounted for about 18% of the total weight of the ingested food. The fish consumed were likely spoonhead sculpins or ninespine sticklebacks.

There were ample supplies of the amphipod Pontoporeia (Hamilton 1973) but only in one area (region 7) were these found in cisco stomachs, and then in very small quantities (Table 22). Small numbers of sphaeriids were consumed in regions 1-3.

Zooplankton intake was high in one region (7) which might help to explain the larger size of ciscoes from station 72A. Koshinsky (1971) suggests that the large size of Trout Lake ciscoes, which are even larger than ciscoes from station 72A, may be attributed to heavy use of existing plankton.

Table 22. Food of ciscoes as percent weight from 6 regions in Southern Indian Lake, 1972.

	Regions					
	1	2&3	4	5	6	7
Mysis	4.9	17.3	6.3	35.3	80.7	19.0
Zooplankton	2.3	4.1	2.8	6.9	4.0	81.0
Mayfly nymphs	80.8	10.4	80.8	-	11.9	-
Caddis nymphs	3.8	1.9	8.1	-	-	-
Immature dipterans	5.3	-	1.5	5.5	3.4	-
Sphaeriids	2.9	1.6	-	-	-	-
Gastropods	-	13.0	-	-	-	-
Unidentified fish remains	-	51.7	-	52.3	-	-
No fish examined	88	111	42	100	69	207
% feeding	44	41	55	53	38	44

6.8.5. Implications of flooding and diversion on lake cisco:

Although from the data lake cisco are not predominant in the same areas of Southern Indian Lake as are whitefish, conditions required for successful spawning are very similar to those of whitefish and the same implications probably hold true. If, as postulated in section 6.7.1, region 6 is a spawning area for ciscoes, the new flow of the Churchill River through this region could disorient migrating ciscoes as well as render old spawning areas unsuitable. As there appears to be little difference between cisco populations within the main lake (e.g. between region 4 and 5) reduction of the flow of the Churchill to regions such as 3 and 4 should show little effect on the ciscoes. The one region where ciscoes are in great numbers, and are larger and in better condition (region 7) will receive the effects of the increased water levels, but not the change in water regime, and it is expected that only minor changes to the population will occur.

6.9. SAUGER

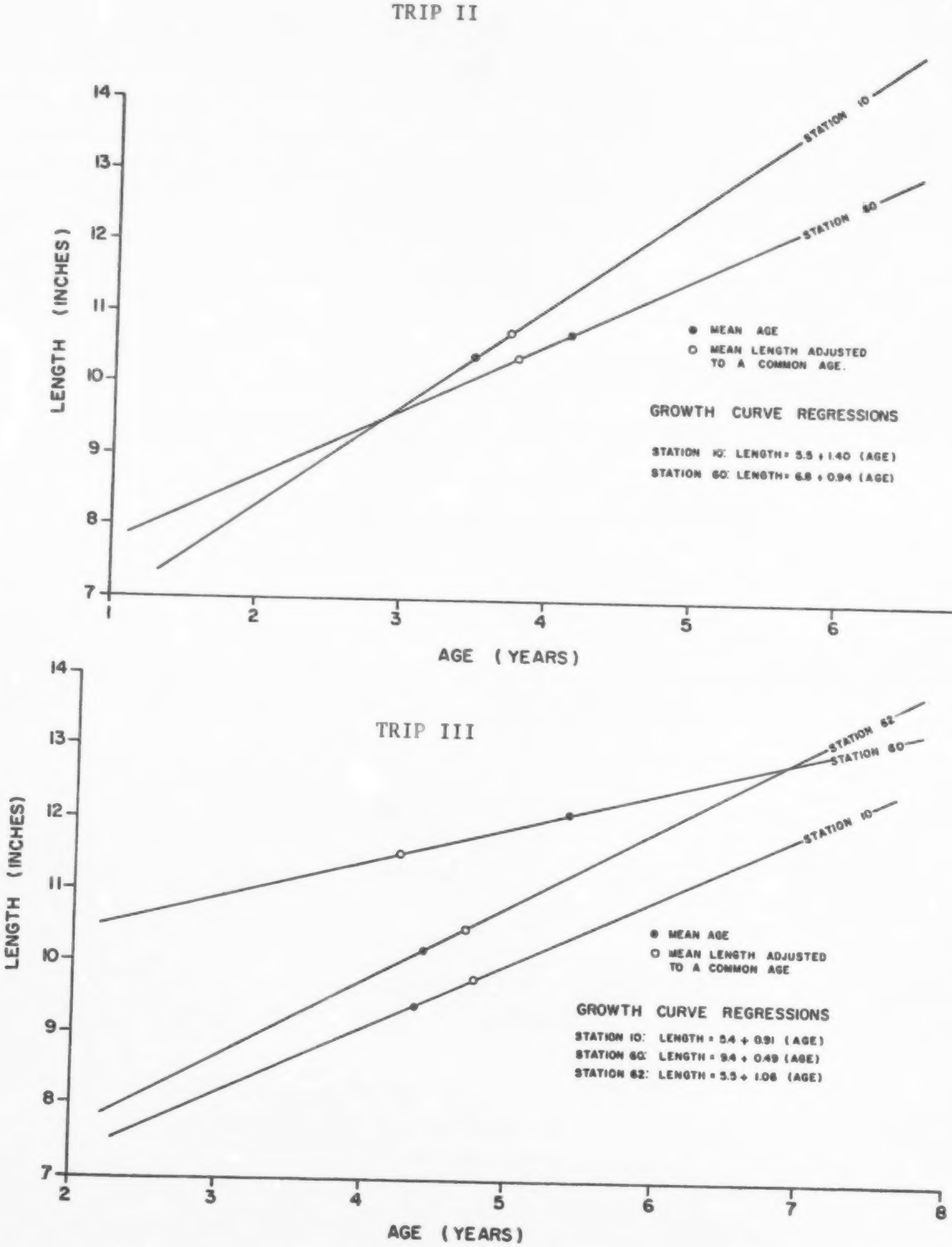
The distribution of sauger in northern Canada is very limited. McPhail and Lindsey (1970) had no reports of sauger in the area of Canada covered by their manuscript and though Rawson (1960) found them in all five lakes on the Churchill that he discussed, he noted that they had not previously been recorded north of the Saskatchewan River. On the other hand, Bajkov (1930) describes sauger as "extremely abundant" in Lake Winnipeg and Lake Winnipegosis. In Southern Indian Lake, sauger appeared frequently at some stations and infrequently at others.

Although sauger is a commercially important species in Southern Manitoba they have not been actively exploited at Southern Indian Lake.

Discussion of the sauger data has been limited to those areas of the lake where the catch was large enough to give results that could be meaningful.

Samples large enough to be analyzed for growth rate (and condition) (i.e. n >20) were taken from stations 10 and 60 during trip II and stations 10, 60 and 62 during trip III.

During trip II and trip III the rates of growth of sauger were not significantly different between stations 10 and 60 (and 62) (Figure 11). Neither were there significant differences in mean ages, or mean lengths in trip II. However, during trip III sauger caught at station 60 were significantly longer at age, and had a mean length and mean age (Table 23) significantly greater than sauger from stations 62 and 10. Obviously during trip III, the sauger sampled at station 60 were of a different



TRIP II

TRIP III

Figure 11. Comparative growth curves of sauger during 2 trips on Southern Indian Lake, 1972.

aggregation than those at either of the other two stations.

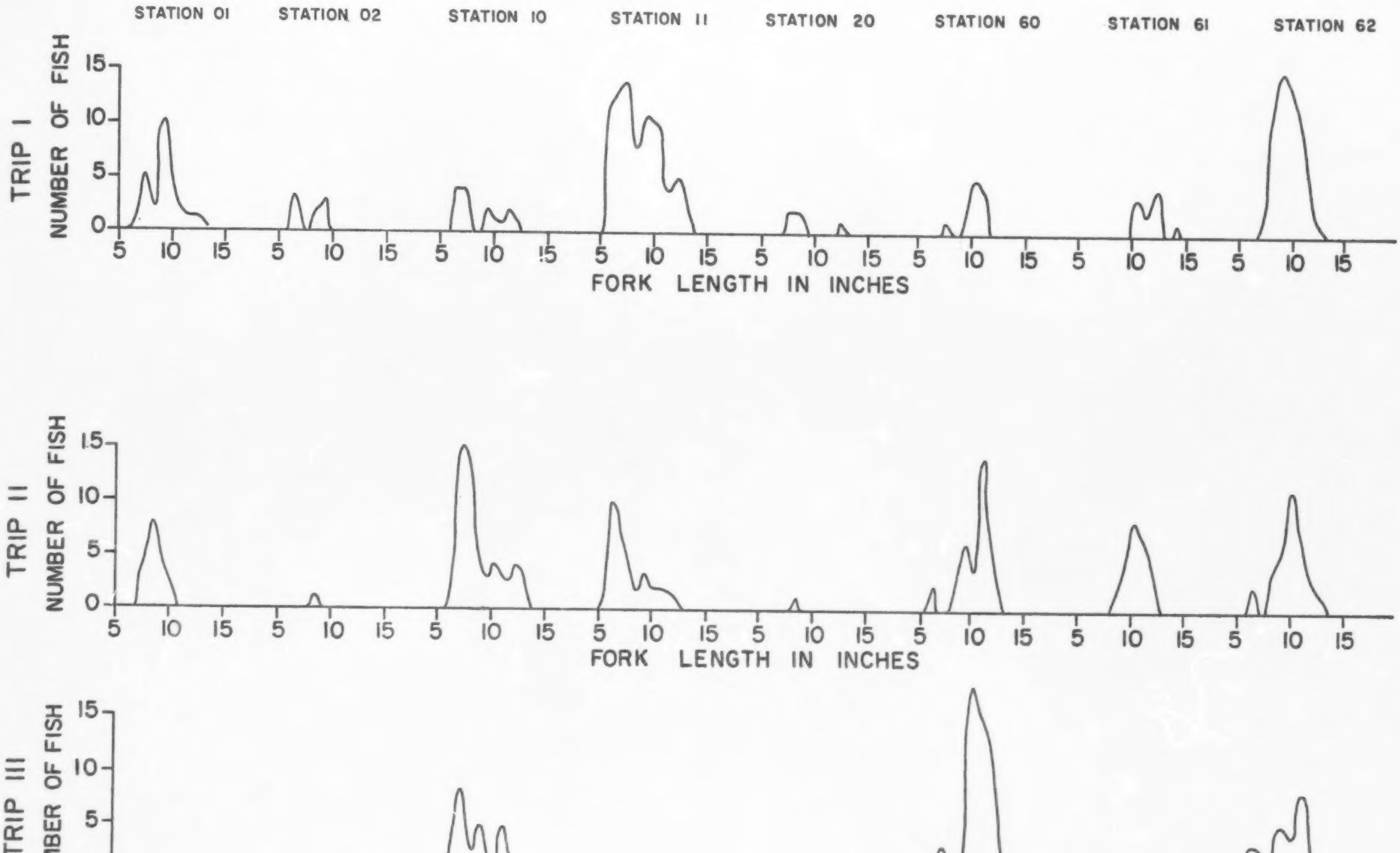
Table 23. Mean ages, lengths and weights of sauger from three stations on Southern Indian Lake, 1972.

Station	TRIP II Mean age (years)	TRIP II Mean length (inches)	TRIP II Mean weight (pounds)	TRIP III Mean age (years)	TRIP III Mean length (inches)	TRIP III Mean weight (pounds)
10	3.5	3.5	9.5	4.4	9.5	0.4
60	4.1	10.9	0.5	5.4	11.6	0.6
62	ns	10.9	0.5	4.4	9.9	0.4

ns - no sample

At station 10 the frequency of smaller sized sauger increased durin the summer (Figure 12) with relatively few fish greater than 10 inches. Another station in region 1 with good sauger catches, station 11, also had a high frequency of smaller sized sauger during trip I and II. At station 60 the frequency of the larger sauger (greater than 10 inches) increased steadily, and at 62, decreased.

Numbers of sauger at these stations changed also. Catch per unit effort of sauger at station 10 increased slightly over the course of the summer, and at station 11 decreased dramatically. At station 60 the increase was 200% between trips I and II and another 100% between trips II and III (Table 24).


STATION 01
STATION 02
STATION 10
STATION 11
STATION 20
STATION 60
STATION 61
STATION 62
TRIP I
NUMBER OF FISH
15
10
5
0
5
10
15
FORK LENGTH IN INCHES
TRIP II
NUMBER OF FISH
FORK LENGTH IN INCHES
TRIP III
NUMBER OF FISH

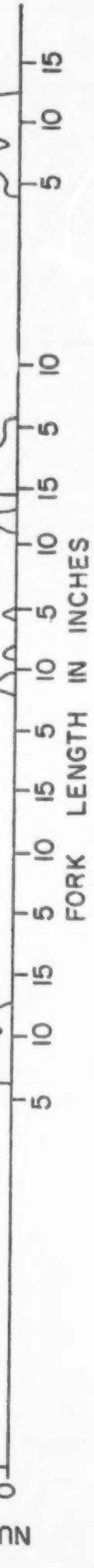


Figure 12. Length-frequency compositions of sauger in Southern Indian Lake, 1972.

Table 24. Catch per unit effort for sauger at 4 stations on Sou Indian Lake, 1972.

Station	Trip I	Trip II	Trip
10	10	20	13
11	63	17	
60	6	17	33
62	24	17	13

ns - no sample

The food of sauger taken from regions 1 and 6 (Table 25) wa similar to that of walleyes taken from the same regions. The diet almost exclusively of fish although some mayfly nymphs were taken region 1. In region 6 trout-perch were found in sauger stomachs e they had been absent in the experimental gillnets.

Table 25. Food of sauger as percent weight by items from two re in Southern Indian Lake, 1972.

	Region	
	1	6
Cisco and/or whitefish	73.2	30.6
Ninespine stickleback	1.0	-
Trout-perch	-	12.9
Sculpin	9.3	-
Perch	-	3.6
Unidentified fish remains	15.4	52.9
Mayfly nymphs	1.1	-
No. fish examined	60	81
% feeding	42	31

Thus, of the areas in Southern Indian that were sampled four stations in particular had sauger in plentiful numbers. From the anal it appears that immediately following the time of spawning (late May t early June) the size of the sauger population, a population of larger, older sauger, increases at station 60, and a smaller size population characterized by smaller, younger sauger remains at station 10.

Comparable rates of growth for sauger from other lakes (Table 2 show that sauger from Southern Indian Lake have, on the average, a slo rate of growth than sauger from elsewhere, including two lakes on the Churchill River system.

Table 26. Rates of growth and positions of Y-intercepts for sauger f three lakes in Canada. Length increments (Y axis) are in inches.

Lake	Slope (growth rate)	Y-intercept
Southern Indian	0.82	6.8
Lake Winnipeg[a]	1.25	4.6
Lake Winnipeg[b]	0.97	7.4
Drinking & Otter[c]	0.97	5.0

[a] Bajkov, 1930
[b] Kennedy, 1949
[c] from Rawson, 1960

6.9.1. Implications of flooding and diversion on sauger:

Although changes within the population of sauger in Southern Indian Lake will occur, except for a possible increase in number of sau in regions where they were previously scarce, these changes will lik not be noticeable. The region of the lake which appears to be most suitable for sauger (region 6) is to receive the full flow of the Ch after the diversion, however, new areas as suitable for this species fish will be created in the flooded regions of 3, 4 and 5.

Priegle (1969) states that sauger are known to spawn in eithe or streams depending upon local conditions but Pollard (pers. comm.) never recorded sauger spawning in streams in Manitoba. If sauger sp in Southern Indian Lake is restricted to sandy shorelines and gravel and reefs the flooding of up to 10 feet could put these sites in wat deep for successful spawning and new shoreline and/or reefs will con uncleared organic debris. Although little is known about the abilit the sauger to adapt to new habitats it seems likely that clearing of shoreline areas for future sauger spawning sites would increase the for maintenance of this species.

6.10. WHITE SUCKER

The white, or common sucker as it is known was present in most areas of Southern Indian Lake that were sampled. It is typically found in a wide variety of lake and stream conditions though in the more northern limits of its range it is usually found in more shallow waters (McPhail and Lindsey 1970). Koshinsky (1965) and Rawson (1959) found white suckers predominantly in the shallow waters of the lake studied. In Southern Indian this was not found to be true for the most part. Except for particular areas near the time of spawning, white suckers were taken in reasonable numbers from depths to 70 feet.

Mean length of white sucker was 13.9 inches and mean weight 1.73 pounds. These white suckers are probably not in quite as good condition as those from other North American lakes (median weight value for length class 13.5-14.3 inches, 1.91 pounds, Carlander 1969).

Catch per unit effort (C.U.E.) was very high at stations 01 and 11 during trip I, then dropped to values similar to other stations during trip II (Figure 13). White suckers spawn in late spring in inlet or outlet streams and along lake margins on shallow gravel areas (McPhail and Lindsey, 1970) and it is possible that the high C.U.E. at particular stations in early July could be the result of a spawning aggregation of white sucker still present. The very dominant length class of suckers at these two stations during trip I (15 inches) which becomes greatly reduced during trip II (Figure 14) is a size consistent with that of mature white suckers (Carlander 1969).

6.10.1. Implications of flooding and diversion on white suckers:

The flooding of Southern Indian Lake could have a detrimental effect on shore-spawning white suckers if areas of clear gravel are not available. However, experience with white suckers in newly flooded reservoirs in the past has been that they react positively to new impoundments, and that an increase in number and size of white sucker, at least initially, can be expected. Following shoreline stabilization, white sucker production will decrease and because of the decrease in nutrients previously contributed by the Churchill River, this decrease will likely be to a level that is less than exists prior to impoundment and diversion.

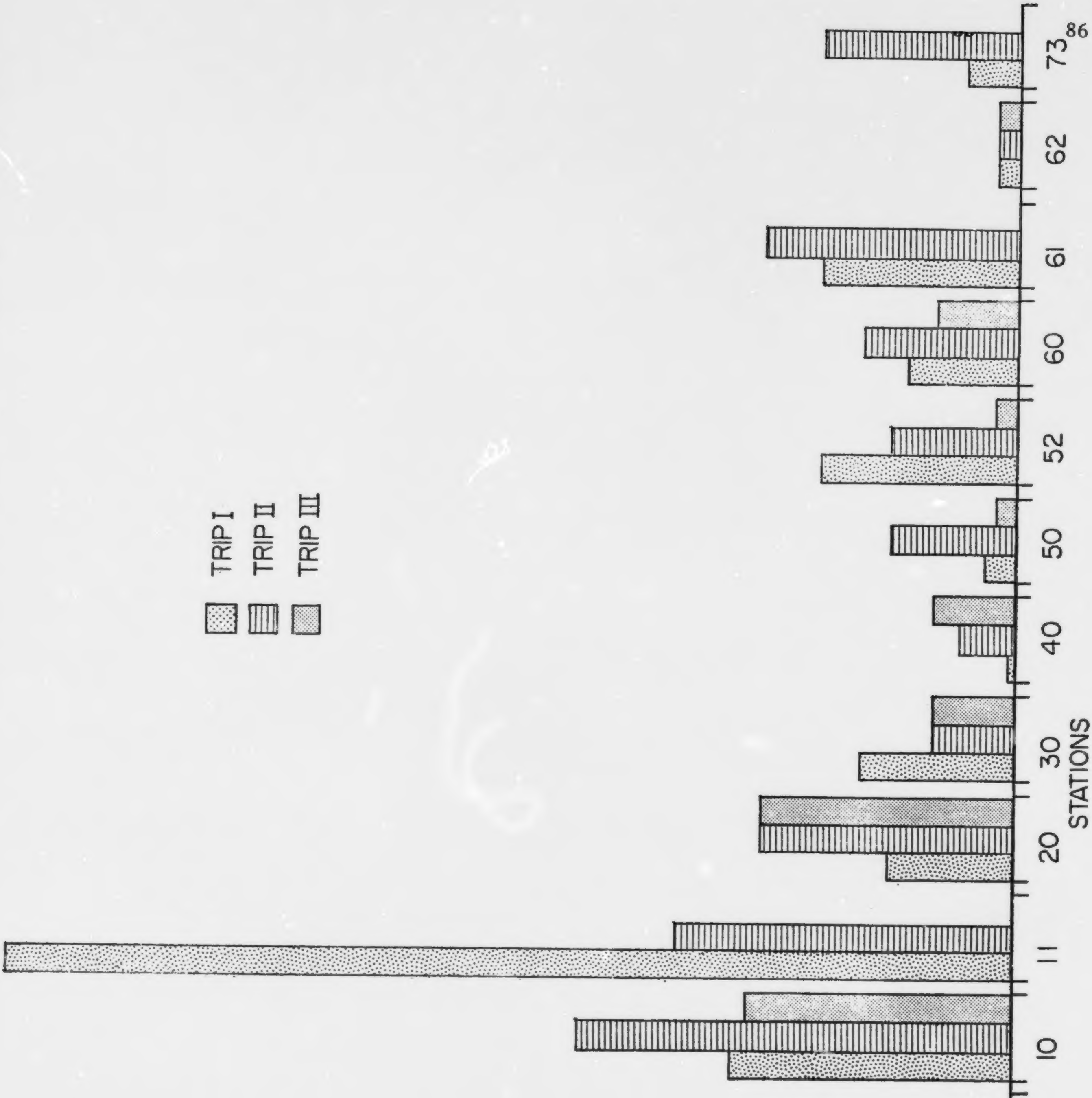


Figure 13. Catch of white sucker from one gang of nets during 3 trips on Southern Indian Lake, 1972.

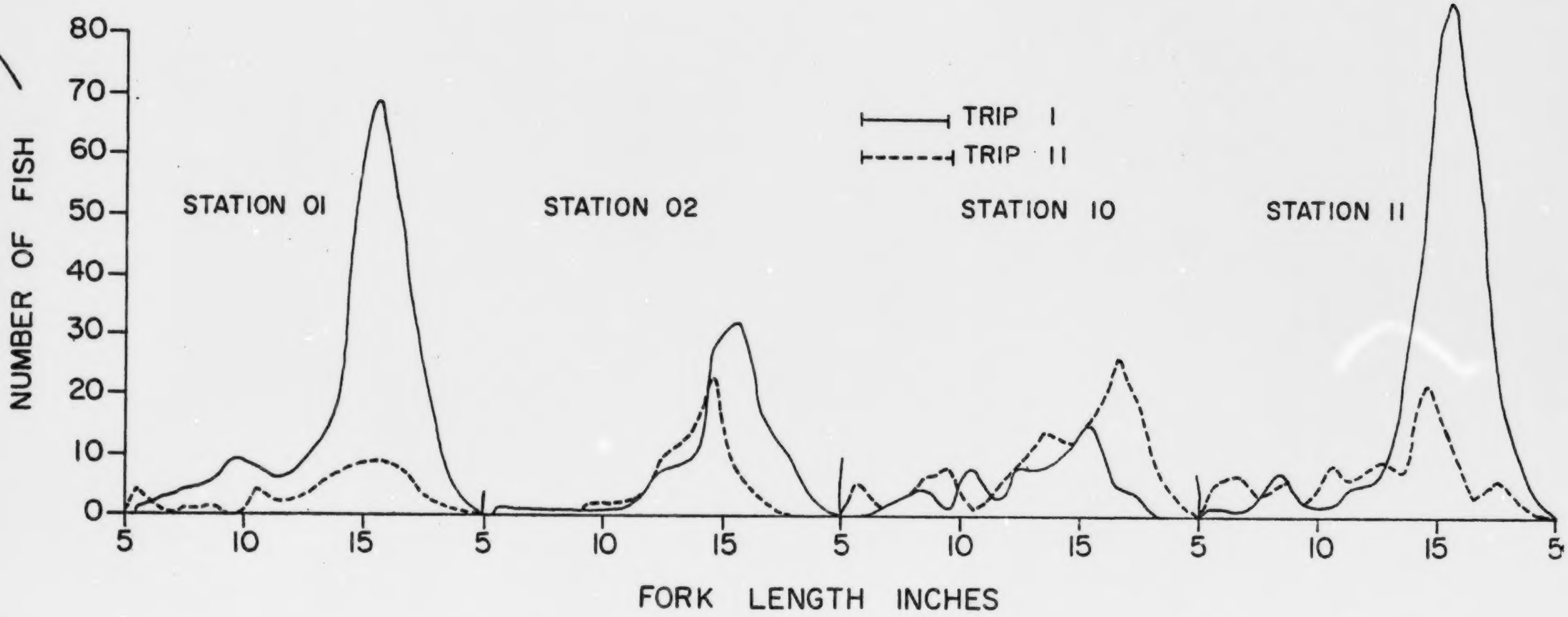


Figure 14. Length-frequency composition of white sucker in Southern Indian Lake, 1972.

6.11. LONGNOSE SUCKER

Longnose suckers were taken from all parts of Southern Indian Lake, though they were very much more prevalent in particular regions. This deep, cold-water species was taken in large numbers from the main lake stations (10, 30, 40, 41, 43, 51) under the direct influence of the Churchill River. It was found in depths from 10 to 100 feet, and appeared more numerous in depths greater than 40 feet. Mean length for the entire sample was 15.6 inches and mean weight 2.4 pounds. Carlander (1969) gives longnose suckers at 15.8 inches a median weight of 2.44 pounds which is slightly lighter than suckers of comparable length from Southern Indian Lake.

6.11.1. Implications of flooding and diversion on longnose suckers:

Although there is a market for longnose suckers, transportation costs from Southern Indian Lake precludes this lake as a source for these fish. However, as the economic value of this species and of other coarse fish species increases transportation costs will become less of a factor and these fish will become more important commercially.

The change of the direction of the Churchill River flow from regions 3 and 4 with subsequent flooding and increasing turbidity could change these regions enough to cause a decrease in number of longnose suckers where they are now in the largest supply. However, regions 1 and 2 should not change markedly, and likely region 6 will improve in terms of longnose sucker habitat, with the result that probably the population of longnose sucker in Southern Indian Lake will not change overall.

6.12. YELLOW PERCH

A very prominent length class of yellow perch of 5.5 to 7.0 inches was present at all stations where these fish were caught (Figure 15). This peak corresponds to an age of about 4 to 5 years and should consist of mature fish (McPhail & Lindsey, 1970). A second peak, dominant at station 53 and present at most other stations consisted of 2 to 3 year olds many of which were immature.

There was no significant difference in growth rates between perch taken at different locations in Southern Indian Lake, and rate of growth in the lake in general appears to be fair. According to McPhail and Lindsey (1970) 3 year old perch from the more southerly Lake Manitoba were 5 inches long and weighed 1 ounce. Three year old perch on Southern Indian Lake averaged 5.25 inches and 1.5 ounces.

MacKay (1963) states young perch are highly dependent on zooplankton and the success or failure of a strong year class is dependent on the availability of this food for the young. Older perch showed a strong preference for mayfly nymphs (Table 27) with mysids and small fish such as sculpins second.

Table 27. Percent stomach contents by weight for yellow perch from Southern Indian Lake, 1972.

Mayfly nymph	33.1
Mysids	17.4
Unidentified fish	22.5
Sculpins	17.4
Amphipods	5.1
Immature dipteran	0.3

Catch per unit effort for perch varied with flow conditions. Perch are seldom found in strong current (MacKay 1963) and areas of Southern Indian where the Churchill was more confined or that flow increased, were almost devoid of perch (Table 28). Perch were taken in depths down to 60 feet.

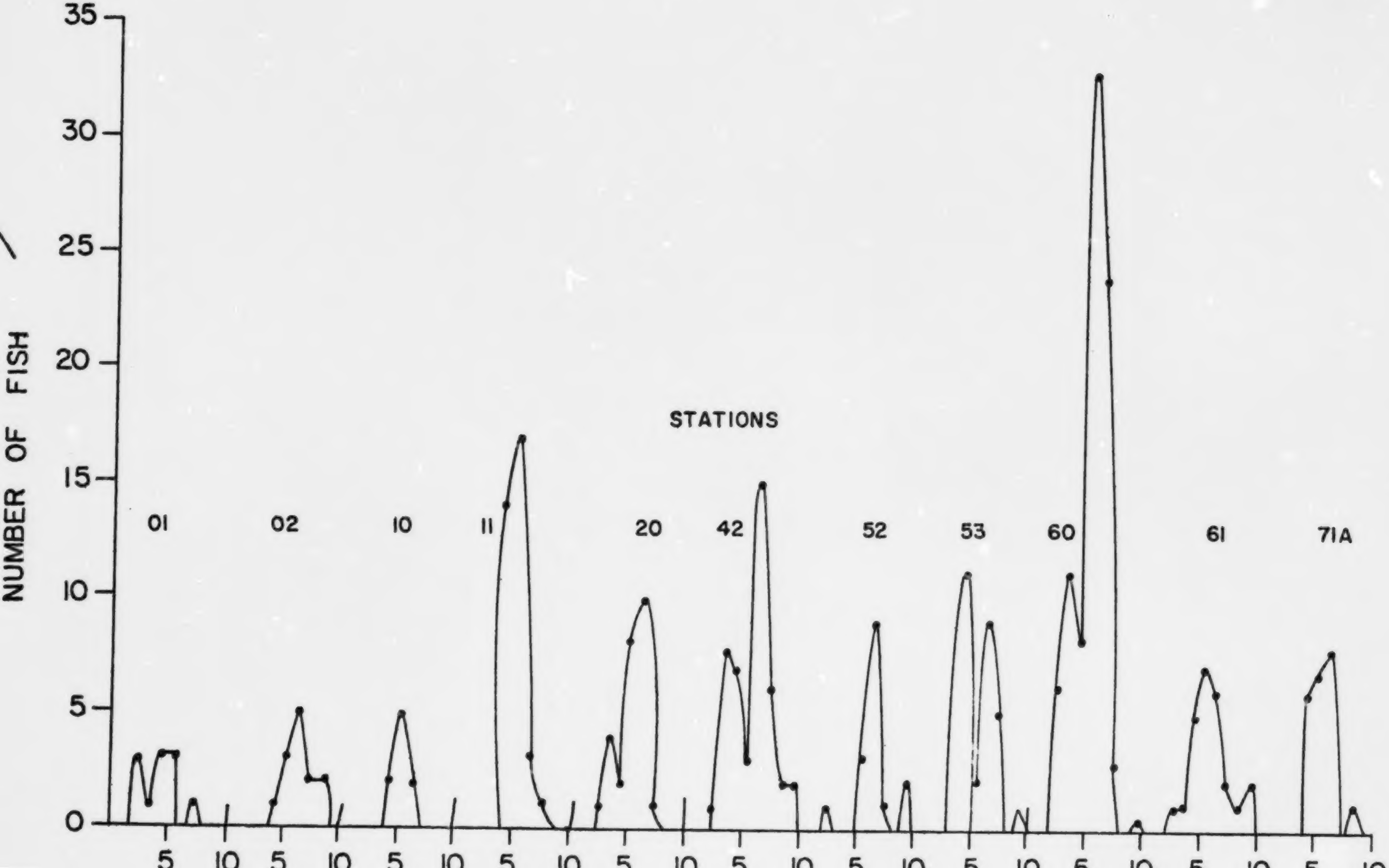
Table 28. Catch per unit effort (C.U.E.) of yellow perch from 21 stations on Southern Indian Lake during the summer of 1972.

Station	01	02	10*	11	20*	30*	31*	40*	41*	42	43*	50	51*	52	53	60	61	62	71	72	73
CUE	3	4	2	14	5	1	3	0	0	13	0	2	0	4	17	16	7	1	12	2	8

* Stations situated at points of major river flow

6.12.1. Implications of flooding and diversion on yellow perch:

Diversion of the Churchill River through region 6 will destroy perch habitat in this region, but should provide much larger areas of quiet water in the remainder of Southern Indian Lake. Flooding of existing shorelines will increase turbidity, and could decrease the dissolved oxygen in the


NUMBER OF FISH
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30
25
20
15
10
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STATIONS
01
02
10
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53
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water, especially under the ice in shallow bays. Perch appear to be tolerant of lower oxygen values, at least more so than walleye, but are not found in large numbers in areas of turbidity or siltation (MacKay 1963).

Probably the flooding will have little effect on the success of thei spawning. Perch spawning areas typically are shallow weedy bays with depth of 5 to 10 feet. Unless siltation becomes a major problem throughout the lake, there should be many areas of shallow weedy conditions ideal for perch spawning.

6.13. TROUT-PERCH

Trout-perch are not economically important fish in themselves b are important as forage fish for sauger and possibly walleye and pike. They are common to slower water areas (McPhail and Lindsey, 1970) but taken from some of the faster flowing areas (station 30) and were abse from obvious regions of quiet waters (e.g. region 6) in Southern India Lake.

Large numbers were not taken from the experimental nets but of taken the mean length was 3.77 inches and mean weight 0.33 ounces. Mc and Lindsey (1970) stated that trout-perch in their area usually did n exceed 4 inches which appears to be the size range of this species in Southern Indian Lake.

6.13.1. Implications of flooding and diversion on trout-perch:

Little is known about many aspects of these fish but it seems unlikely that there will be little adverse affect on this species. The be either lake or stream spawners and although changes will affect sho spawning areas, at least temporarily, new spawning areas in the streams will be available. Although the food of trout-perch (plankton) will li drop in number in regions 3 and 4 significant (Patalas 1974) food does not appear to be the limiting factor under present conditions and it is unlikely that the trout-perch population will decrease as a direct resu of this adverse effect on the plankton.

6.14. BURBOT

Burbot are not plentiful in Southern Indian Lake, occurring in equal numbers throughout the lake except in region 6 where none were taken (Table 29). Region 6 is a relatively shallow bay, with warmer than elsewhere in the lake (Cleugh 1974), habitat which, according to McPhail & Lindsey (1970) is not preferable for burbot. Elsewhere in lake burbot were taken at varying depths, usually greater than 20 fee most often about 60 feet.

Table 29. Catch per unit effort (C.U.E.) for burbot from 13 stations Southern Indian Lake during trip II, 1972.

	Station										
	01	10	11	20	30	40	43	50	52	71A	72
CUE	2	-	2	1	2	3	2	11	5	6	3

With a mean length of 22.35 inches and mean weight of 2.64 poun the burbot from Southern Indian Lake appear to grow more slowly than i typical of burbot from other North American lakes (mean weight of 3.5 p at 22-23 inches, Carlander, 1969).

Of the burbot examined the prime source of food was other fish w percentages by weight being: cisco 41.8%, cisco and/or whitefish 24.4% trout-perch 7.3%, perch 6.8%, sculpin 4.6%, ninespine stickleback 4.2%

unidentified fish remains 10.9%.

6.14.1. Implications of flooding and diversion on burbot:

Burbot are known to spawn in swift water of streams and gravel shoals of lakes (MacKay 1963) in from 1 to 3 feet of wa diversion is unlikely to adversely change the habitat for burb of uncleared land will temporarily reduce the spawning sites t streams entering Southern Indian Lake.

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6.15. GOLDEYE

Although McTavish in 1952 recorded no goldeye from Souther
Lake he noted that they were reported to be in the lake, and that
fishermen were taking some from Opachuanau Lake. The research cr
were unsuccessful in their attempts to take goldeye in the experi
until directed by a native to try in the vicinity of station 62 w
goldeye was taken. From this it is apparent that there are a few
in isolated areas of Southern Indian Lake. According to McPhail a
Lindsey (1970) they inhabit turbid shallows of lakes and ascend ri
tributary streams to spawn. At present turbid shallows are not pl
in Southern Indian Lake, however, following flooding and the diver
larger areas of the lake are liable to become much more turbid as
lines are carved from existing clay banks. The new Southern India
may provide greater areas for goldeye and this species could incre
number.

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6.16. Recommendations

1. Under the interim licence it will be possible for M
to decrease the flow through Missi Rapids to a yearly minim
(from 30,000 cfs). This will substantially decrease the inf
nutrients to region 4 contributed by the Churchill River, th
decreasing productivity in this region. To maintain basic p
this part of the lake at an acceptable level it has been rec
(Hecky _et.al._ 1974), that a mean annual flow of 5000 cfs be
Missi Rapids. Considering the importance of region 4 to fis
crop and commerical yield) this recommendation is strongly s

2. Sites for future spawning beds for whitefish, and p
and shore-spawning sauger could be prepared prior to the flo
Indian Lake. Such sites for whitefish as formulated by Weag
(1973) and cisco would consist of large boulders, and bedroc
cleared and grubbed to the rock base. For sauger (and possi
spawning walleye) spawning beds would consist of cleared and
of shoreline that will be sandy, or gravel shores or ridges
water regime. Although artifically prepared spawning sites
the mature fish, prior clearing will speed the natural force
and will ensure that some type of spawning site is available
fish populations.

3. Monitoring of Southern Indian Lake and its fishery s
maintained following impoundment to determine.

i) effect of the flow of the Churchill on fish in re
ii) extent of fish movement from Southern Indian Lake
Rat River System.
iii) the effect that the reduction of flow of the Chur

through regions 3 and 4 will have on such parameters as food and habitat for fish.

iv) the effect of increased water levels in all regions on the fish, but in particular those regions (0, 1, 2, 5 and 7) that will remain unchanged relative to the Churchill River flow.

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6.19. APPENDIX

Report on the 1972 Fishing Survey on Southern Indian Lake, Manitoba

by

Johann Sigurdson

APPENDIX

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1. INTRODUCTION

The summer of 1972 was the first summer of field work for the fisheries section of the Churchill-Nelson River diversion project carried out by the Department of the Environment, FRB of Canada, Freshwater Institute. The summer's work for the fisheries crew was to concentrate on systematically fishing Opachuanau and Southern Indian Lakes.

The lakes were divided into seven major areas but with only six major stations. (Since this inception station 72 has almost attained major station status in the fisheries data.) The seven areas were chosen mainly because of geographical boundaries but also for convenience in identification of areas in subsequent data. The major stations were in a series of tens, e.g. 10, 20, 30, 40, 50, 60. The minor stations in each area had the first digit of the major plus another from 1-9. In special cases in the data some of these stations were identified with a letter, e.g. 72A, 72B. These indicate the order of occurrence when duplicated within the same trip. The six major stations plus fifteen more which were chosen randomly to cover each area were used as the twenty-one fishing stations.

The original plan was to fish each of the 21 stations three times over the summer season. In actuality there were two trips completed and the third trip consisted of the major stations and three others; 72, 62 and 52. The trips were divided as follows during 1972:

Trip I	Day 179-199
Trip II	Day 216-241
Trip III	Day 242-253

To facilitate later data processing a number code was devis record fish species. These were as follows:

1 - whitefish
2 - pickerel
3 - pike
4 - white sucker
5 - longnose sucker
6 - burbot
7 - cisco
8 - sauger
9 - perch

The rarer fish caught or the smaller species were not coded field but have since been coded by the Computer Centre and they are follows:

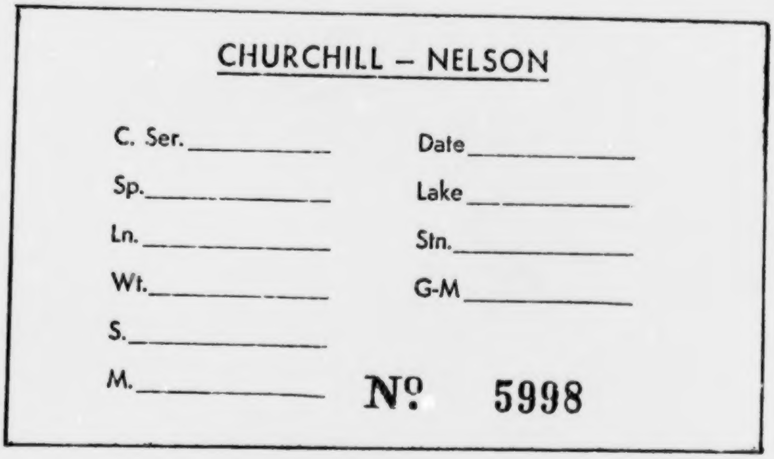
10 - trout-perch
11 - sculpin
12 - spot-tail shiner
13 - unknown (unidentified in the field)
14 - goldeye

2. METHODS OF RECORDING DATA

2.1. Scale envelopes:

The scale envelope was used where a scale sample was taken and t data for an individual fish were entered directly onto this card. Note example 1 below.

Example 1.



CHURCHILL – NELSON

C. Ser.__________ Date__________
Sp.__________ Lake__________
Ln.__________ Stn.__________
Wt.__________ G-M__________
S.__________
M.__________ №. 5998

An important feature was the Catch Serial Number in the upper left corner. Each mesh size for each set had a different number. It was a 4-digit number beginning in 0,e.g. 0001 was the first, 0002 the second, etc. The numbers for Swedish nets all started with a 9 and were also 4 digits, e.g. 9001.

Also important was the scale envelope number which later allowed the individual fish to be found after the aging work had been

This feature was only available on the second and third trips

cards had been used previous to this.

2.2. The fish card supplement [example 2]

This card was used when an incomplete analysis was done

serial number was carried over to this card for each mesh of e

Basic data from fish which were completely analyzed were also

from the scale envelopes to give complete basic data on one ca

fish caught from one mesh. See example 2 below.

Example 2.

CHURCHILL-NELSON FISH CARD SUPPLEMENT

C. Ser. No.			C. Ser. No.			C. Ser. No.		
Sp.	Fork L.	Rd. wt.	Sp.	Fork L.	Rd. wt	Sp.	Fork L	Rd. wt.

d.
bered

atch
set.
here
ll

. Ser. No.	
k L.	Rd. wt.

2.3. The master sheet [example 3]:

This sheet summarized all the data collected for the day.
7 columns for the major species and 4 columns for minor species.
numbers along the left margin correspond to the mesh sizes set.
7 rows indicate the shallow set and the last 7 rows indicate the
The depths at the end of each mesh size appear in the second and
columns.

Station number, lift day, and time set and lifted appear a
of the sheet. Catch serial number for each mesh size appears bel
the right of this. In the lower left corner of the sheet the tota
of fish caught that day is shown over the total number of pounds c
These figures for individual species are along the bottom of the s
A master sheet for Station 40 is attached as example 3. Along wit
master sheet a map of the area was prepared showing the relationsh
the shoreline to the gang of nets and to the mesh sizes. There wa
a short note on procedures for the day and on general observations

There are
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made.

Example 3 Master Sheet

CATCH RECORD

Page ___

Card	Year	Lake	Stn Lift		Time	
				Day	Set	Lift
1	2	1	40	251	1900	0800

	Mesh	Depth		Whitefish		Walleye		Pike		W. Sucker		L. Sucker		Burbot		Cisco		Catch	Trout-perch		Sculpin	
	Size	M	M	No.	Lbs	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	No.	Lbs.	Ser. No.	No.	Lbs	No.	Lbs.
1	99	5.5	5.5	7	5.08	1	0.44	2	3.69	7	8.63	4	18.31					9074	1	0.01	1	
1	15	6.0	6.0	9	6.03			3	9.69	2	0.27							0542				
1	20	6.0	5.5	12	10.37	1	2.94	1	2.69									0543				
1	28	6.0	5.5	9	11.24	1	0.63	1	3.00	8	9.97	1	1.88					0544				
1	35	5.5	6.0	5	7.31			4	12.94	5	8.13	4	11.19			1	1.38	0545				
1	42	6.0	6.0	7	14.63			3	16.19	4	8.06	4	32.13					0545				
1	52	3.5	6.0	2	5.69			1	15.0	1	3.44	8	30.38					0547				
3	15	14.0	15.0	17	7.35							4	8.46			1	0.14	0548	1	0.01		
3	20	15.0	15.0	34	24.91							5	7.61			1	0.22	0549				

3. FIELD METHODS

A fifty foot converted trapnet boat, the "M9", belonging to the Manitoba Department of Mines, Resources and Environmental Management, was used as a base and as such was utilized for sleeping and eating accommodation for a fishing crew of 5 as well as for 2 crew members of the morphometric team. It was also used to carry gasoline and supplies for three other boats; 2 - 19 foot steel yawls and a 16 foot aluminum runabout. This mobile base camp was moved almost daily.

A "standard gang" of nets consisted of 6 - 50 yard nylon nets joined with bridles to make up one almost continuous net 300 yards in length. The 6 mesh sizes were expressed in a number code as follows:

1 1/2" - 15
2 - 20
2 3/4" - 28
3 1/2" - 35
4 1/4" - 42
5 1/4" - 52 (stretch size)

These mesh sizes were always kept in the same order as follows: 52-15-42-20-35-28 or in other words largest-smallest-2nd largest-2nd smallest-3rd largest-3rd smallest. At each station where possible one of these gangs would be set in a shallow location, and one would be set in a deep location. Originally it was planned to set three gangs but after two days this proved to net too many fish to handle efficiently and so the number was reduced to two gangs. The shallow set would be generally between 3-7 meters and the deep set 8 or more meters. Also, where possible, a "Swedish" net, a specially designed single test net consisting of 12 mesh sizes from 3/4"-6" and 40 yards long, was set. This practice however was precluded in many cases because of bad weather and high winds which broke the delicate and fragile net. All sets were bottom sets.

Sets were usually located within a one-mile radius of the station and were chosen for the following reasons:

a) High winds made setting in the lee of an island, point, or bay almost mandatory. The sets were with the wind in these cases.

b) If the area was fairly shallow the deep set was made in the first deep area located.

c) If the area was deep the shallow set was made in the first shallow area located.

d) If bad weather was expected the next day the set was made where it would be sheltered.

e) If an area was known to be exceptionally deep, the deep set was made there. This happened at stations 50 and 30.

f) Areas were randomly chosen to sample weedy, rocky, and sandy shorelines.

g) Where a tributary was located a net was usually set across the current (but not in the stream).

h) Areas were chosen after consulting topographic maps of the lake.

The gangs were usually set around 17:00-18:00 and lifted at 08:00-09:00. On a few rare occasions because of inclement weather they remained set for two nights. Also on a few rare occasions because of high winds only one gang was set, usually the shallow, in the lee of the shore.

With a full fishing crew, two crew members in a yawl would usually be responsible for the setting and lifting of one gang. All the meshes were kept separate by placing the fish in different tubs labeled by mesh size. These fish were taken back to the "M9" to be recorded. The basic data taken were as follows: fork length, weight, sex. These were recorded on the supplement card except in a few rare cases where the fish were counted and weighed 'en masse'. As well, on the first ten fish of each species from each mesh size the following were taken: scale sample, stomach sample, possibly fin clips from suckers and whitefish and otoliths from burbot. Only the stomachs which were full were preserved when it was possible to ascertain; such as in pike, pickerel, sauger and burbot. In the whitefish, suckers and cisco all stomachs were preserved.

For specimens from which a scale sample was taken the data were recorded directly onto a scale envelope. For all others it was recorded onto the supplement card. The data on the scale envelopes were later transferred to supplement cards also and then these data were summarized onto the master sheet. With this master sheet was also placed a rough map of the location of the sets, the relation of the mesh sizes, the location of the Swedish nets, depth at the end of each mesh, duration of set, and the temperature gradient and location taken. There was also a short note on procedure during the day and some observations on the general conditions of the day.

The fish taken by the Swedish nets were weighed and measured only.

Later in the field season when staff became short only a certain mesh size per day from each gang were analyzed. These were chosen for the following reasons:

a) If a mesh size contained many of a species which was fairly rare such as sauger or perch it was done to record these fish.

b) If a mesh size contained many large individuals of a species it was done (e.g. pike, burbot).

c) If a mesh size contained many small individuals it was done to record these fish (e.g. pike).

d) If the gangs contained basically the same species composition the large meshes were analyzed from one gang and the small meshes from the other.

e) If the catch was small all the fish were completely analyzed.

In the cases of partial catch analysis fish from the rest of the meshes were weighed and measured only.

Fish were disposed of by the following methods:

- given to the local people for dog food;
- consumed by the fishing crew;
- fed to seagulls and predators;
- buried on shore;
- some specimens were preserved and brought back to the lab.

The gangs of nets were completely replaced for the second trip, and the 52 mesh was again replaced for the third trip.

Table A. Total number and total weight of all fish species taken in the experimental gillnets at specific stations on Southern Indian Lake, 1972.

Station	Total number	Total weight in pounds
01	559	856
02	621	845
11	972	1372
10	889	1206
73	279	398
72	830	1065
71	516	707
61	566	599
60	896	899
62	406	252
20	1487	1746
31	490	878
30	821	1451
41	595	1014
42	611	839
53	458	533
50	1030	1616
52	653	680
51	691	1102
40	974	1580
43	607	1316
Grand total	14,951	20,954

Table B. Total number and total weight of individual species of fish taken from Southern Indian Lake, 1972.

Species	Total number	Total weight in pounds
Whitefish	3,500	4,613
Walleye	1,556	1,951
Pike	1,309	3,374
White sucker	2,618	4,684
Longnose sucker	1,457	3,702
Burbot	203	952
Cisco	3,433	1,344
Perch	381	95
Sauger	494	239
Grand total	14,951	20,954

Table C. Total number (No.) and total weight in pounds (lbs) of 9 fish species caught at specific fishing stations in Southern Indian Lake, 1972

Stn	Whitefish		Walleye		Pike		White sucker		Sturgeon sucker		Burbot		Cisco		Perch		Sauger	
	No.	lbs	No	lbs	No.	lbs	No.	lbs	No.	lbs.	No.	lbs.	No.	lbs.	No.	lbs.	No.	lbs.
1	42	59	50	51	27	72	309	537	45	97	4	3	38	25	11	1	33	11
2	9	12	189	206	88	219	184	320	–	–	–	–	129	81	13	3	9	4
1	75	90	56	59	48	144	533	926	16	25	4	13	79	32	44	9	117	74
0	149	158	50	52	29	84	299	565	106	228	11	37	161	54	9	1	75	27
3	60	59	54	58	51	124	66	120	5	13	2	10	18	8	23	6	–	–
2	16	32	151	397	63	198	31	36	–	–	12	41	543	355	9	1	5	5
1	142	211	13	16	74	206	58	56	1	6	16	46	484	159	23	4	5	3
1	25	32	127	130	38	81	142	248	7	18	–	–	172	66	25	8	30	16
0	73	77	157	186	122	263	125	243	1	3	–	–	238	68	86	10	94	49
2	50	47	30	29	35	70	10	12	1	1	–	–	174	49	4	1	102	43
0	475	597	43	39	109	260	195	428	81	232	22	98	225	81	26	5	11	6
1	136	169	23	29	99	269	58	109	84	243	8	31	70	25	12	3	–	–
0	245	228	50	34	71	178	97	175	278	793	7	17	68	25	4	1	1	.01
1	248	311	8	8	98	242	43	77	117	292	10	44	71	40	–	–	–	–
2	206	244	10	7	36	71	100	166	60	158	25	117	122	45	44	31	9	.01
3	64	57	208	257	23	66	64	135	1	2	–	–	68	8	29	7	1	2
0	467	809	86	100	97	276	44	112	60	167	27	75	247	77	2	0.1		
2	54	84	180	194	51	138	72	128	23	58	8	19	247	55	16	4	2	0.1
1	271	431	28	24	35	88	29	53	142	369	19	88	167	49	–	–	–	–
0	507	685	14	10	70	205	48	49	214	505	21	87	100	39	–	–	–	–
3	186	221	29	65	45	120	111	189	215	491	7	226	12	5	1	0.2	1	0.3
	3,500	4,613	1,556	1,951	1,309	3,374	2,618	4,684	1,457	3,702	203	952	3,433	1,344	331	95	494	239

APPENDIX 5 - VOL. 1 -

THE FISHERIES OF SOUTHERN IND
EXPLOITATION AND REPRODUC

THE FISHERIES OF SOUTHERN INDIAN LAKE
EXPLOITATION AND REPRODUCTION

by

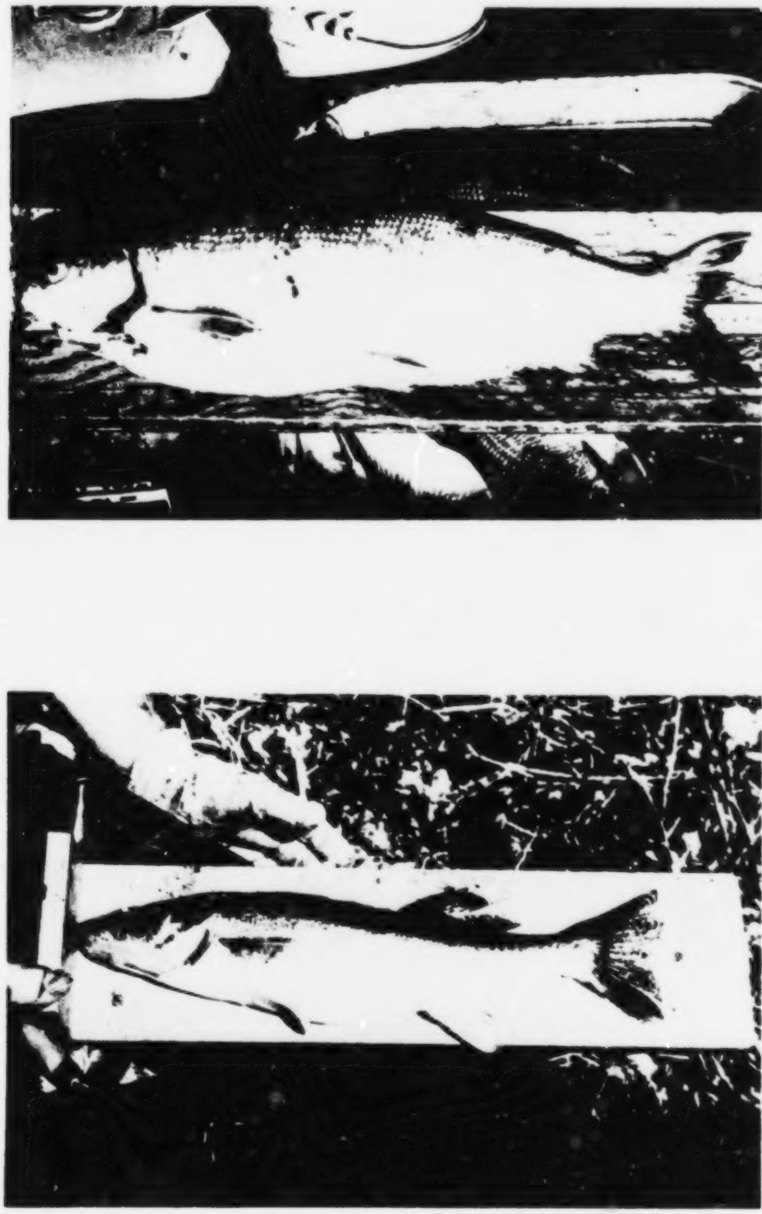
K. V. WEAGLE and W. BAXTER
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
October, 1973

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.



Frontispiece: The prized fish of Southern Indian Lake; top, 6 lb. 9 oz. jumbo whitefish; bottom, a 3 lb. walleye.

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The authors would like first to express their appreciat to all the fishermen on Southern Indian Lake who cooperated wit our questioning, assisted us with the collection of data for th report and the Revenue-Expenditure Analysis. Without the fishermen's cooperation this report would not have been possible. We would also like to express our thanks to Mr. Dan Topolinski, Mr. Alex Cumberland, Mr. Gene Cumberland, Mr. Ryan Brako, Mr. Jim Senka, Mr. Joe Sigurdson, Mr. Bob Cameron, Mr. Randy Winkworth, and Mrs. Dawn Barnes who assisted in the collection and compilin of data.

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I INTRODUCTION

This report is intended to provide exploitation and repr duction data on the fishery of Southern Indian Lake. It is pres ted in fulfillment of the requirements of Task G of the Fisheries Limnology Group of the Lake Winnipeg, Churchill and Nelson Rivers Study. The importance and size of the commercial fishery in Southern Indian Lake put this study high on the authors' priority list, with the result that more work on reproduction and exploita tion has been done here than in any of the other study areas.

The report deals in varying degrees with all aspects of commercial fishery including a revenue-expenditure analysis of in vidual operators. Although cost analysis studies were not precis outlined in the terms of reference, it was felt that production closely related to the economics of the fishery (i.e. if the pric was high more men would fish) and therefore should be included in any study of expoloitation. The economic analysis is in places unsophisticated, but it appears to be more factual than any other available for a northern Manitoba fishery.

The sport fishing analysis attempts to shed light on the potential of the area, however, potential in many sport fisheries can be overshadowed by the ease of access.

During any field investigations you are at the mercy of t elements and spawning studies are no exception. The attempt to s the whitefish spawning run during the fall of 1972 was plagued by bad weather. Although only limited data were collected in 1972, continuing the study in 1973 would have produced little new information. The walleye spawning survey was more successful even though the run at the north end of the lake was missed.

The impact of the hydro project is only superficially dealt with in the report. This can be better treated when all the tasks of the Fisheries-Limnology Group have reported and their finding amalgamated.

2 TERMS OF REFERENCE

Under the original study proposal Task Group G (Fish Production) was responsible for individual tasks 401, 402, and 40 These tasks were outlined in a memorandum from G. D. Koshinsky to A. L. Hamilton on December 10, 1972 as follows:

TASK 401: FISH PRODUCTION

Catalogue spawning and rearing (nursery) sites according to location, depths, substrates, etc., for the major species, at least for representative locations. Document spawning migrations Identify critical factors in recruitment. Considerable work required also in Lake Winnipeg outlet lakes.

Strong interaction with Task 502.

TASK 402: COMMERCIAL FISHERIES

To sample the commercial fishery for location, depth, substrate, catch/unit effort, catch composition, and such parameters as may be applicable to Task 400.

TASK 403: SPORT FISHERIES

To sample the regional sport fishery generally as per Task 402.

3 STUDY AREA

The study area included all of Southern Indian Lake from Opachuanau Rapids to Missi Falls, Opachuanau Lake and the Church River from Leaf Rapids to Opachuanau Lake. Because of their importance as spawning and rearing areas for certain fish species lower stretches of many of the tributaries of these two lakes we also included.

4 SPAWNING

4.1 Whitefish spawning:

4.1.1 Introduction:

Whitefish (*Coregonus clupeaformis*) make up over 90% commercial fish taken on Southern Indian Lake; it is very i therefore, to be able to predict what may happen to whitefi spawning runs after the diversion and rise in elevation. T has been little research done on whitefish spawning and the ture only contains scattered references to the physical cha istics of spawning beds, ie. depths, substrate, etc. Becau the lack of impact assessment studies on northern reservoir past there is similarly limited information on the effect o water levels on whitefish spawning opportunity. Whitefish is also complicated in northern areas by the possible exist two species (Lindsey, 1963) which are similar in external a ance and the possibility that spawning occurs every two or years rather than annually (Kennedy 1953). With the above in mind an attempt was made to try to predict the impact of diversion and raised water levels on whitefish spawning.

4.1.2. Methods:

The whitefish spawning study was centered in Loon Na during the fall of 1972. Between September 22 and October 1 29 gangs of nets were set. For a limited time the standard consisting of six stretch meshes (1.5 inches, 2.0 in, 2.8, 4.3 in and 5.3 in) was used, supplemented by smaller gangs sisting of 3.5 to 5.3 in. stretch mesh. Later in the stud the latter gangs were used because the smaller meshes yiel whitefish. The first ten sets were randomly set, at vario and over different substrates, to try and find where the w were concentrated. Most of the later sets were over large rock where whitefish seemed to concentrate. In these late one end of the net was tied to shore to try and determine distribution of the spawning fish. The locations of the se shown on Figure 1. More sets which might have improved the were precluded by bad weather and limited manpower.

A total of 763 whitefish were examined during the s Sex, maturity, length and weight were taken from all fish. hundred and sixty-one fish were aged by means of scale samp ovaries were taken from 42 mature females. Catch statistic summarized in Appendix I.

Fish maturity was divided into four categories for males and females.

Immature fish were those that did not appear ready during the present year. No other method, except physical a ance of the gonads, was used to determine immaturity. There numerous females which were much larger than the smallest ma female, but they were still classified as immature. These f have been spawning every 2 years and were therefore physiolo immature.

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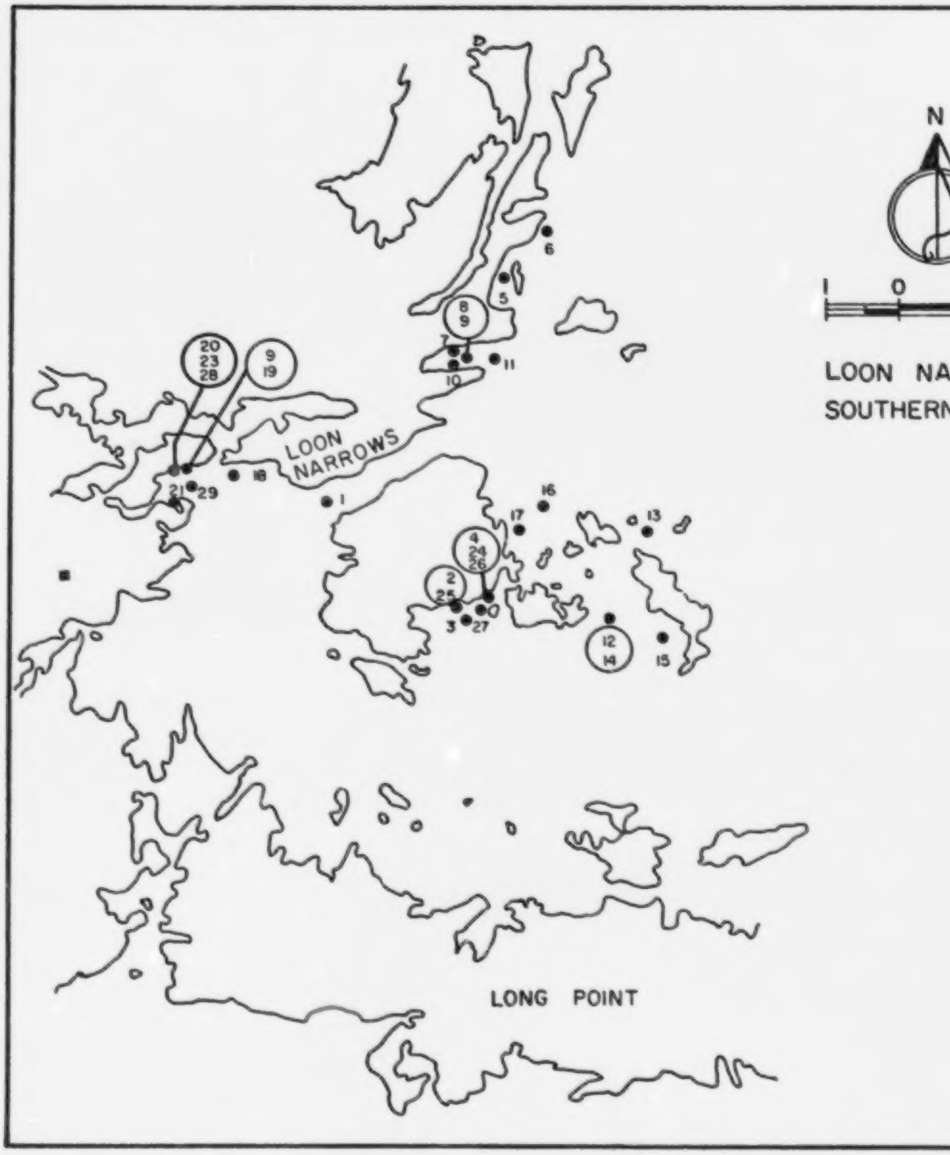
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Figure 1. Location of the net sets during the whitefish sp
study, Loon Narrows, Southern Indian Lake, 1972

Mature fish, both males and females, were those that appeared to be capable of spawning during the present season. The testes of the mature males were much enlarged and their heads and bodies were usually covered with nuptial tubercles (Plate 1). The ovaries of the females were much enlarged, usually a pink color, and they contained well-formed eggs (Plate 2).

Ripe was used to describe fish that were ready to spawn. Ripe males would emit milk if pressure was placed on the abdomen. Ripe females would similarly emit eggs. When ripe, the eggs passed from the ovaries into the body cavity of the females.

Spent was used to describe fish that had already spawned and were devoid of eggs and sperm. At times these fish were difficult to separate from immature fish. The testes of spent males were very small and contained little sperm (Plate 3). The ovaries of spent females were smaller than those of mature fish but contained small white eggs. The body cavity of spent females often contained some eggs (Plate 4).

The average number of eggs in the ovaries of the females was determined volumetrically. The volumes of three subsamples of 300 eggs were measured to 0.10 ml. Then the total volume of the ovary was measured, and the average number of eggs/milliliter was multiplied by the total volume of each ovary to estimate the total number of eggs per female.

Air temperature, water temperatures and weather conditions

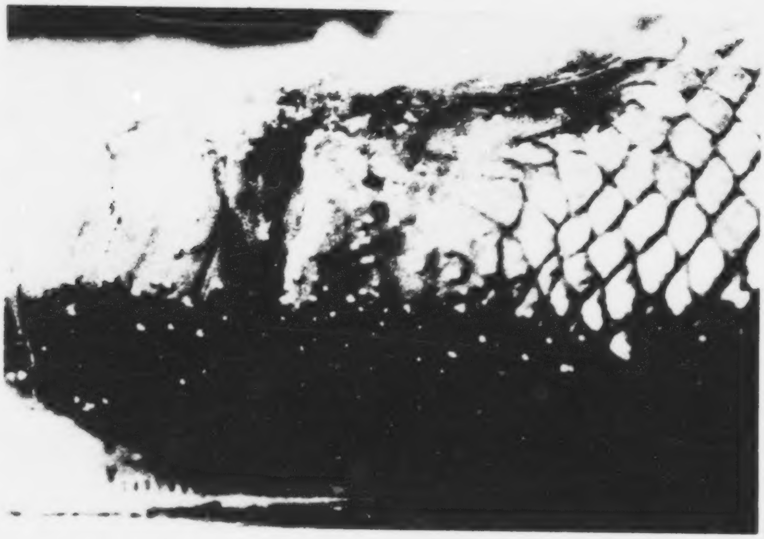


Plate 1. A mature male whitefish showing the nuptial tubercles.

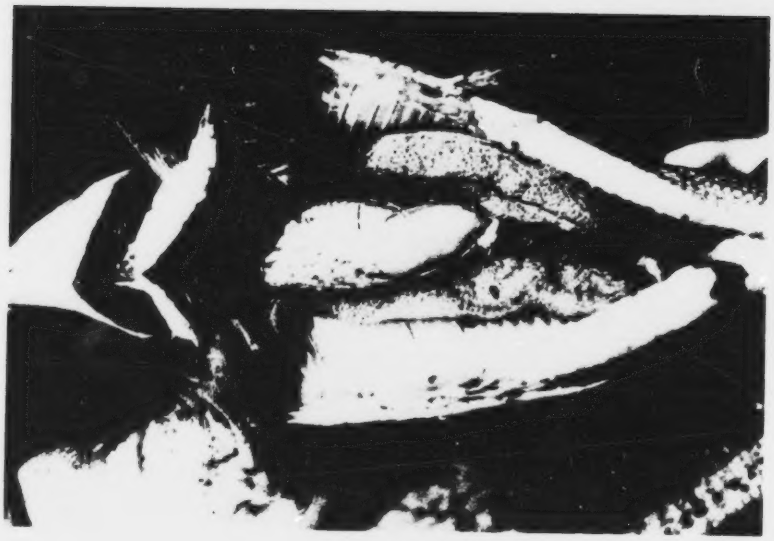


Plate 2. A mature female whitefish showing the ovaries.

Plate 3. A spent male whitefish showing the small testes.

Plate 4. A spent female whitefish, note the small size of the ovaries and the eggs which were shed into the body cavity.

were noted on the setting and lifting of each net. Notes were kept on the number of fish per species other than whitefish netted during the study.

4.1.3 Age and size distribution of spawning fish:

Table 1 summarizes some minimum lengths and ages of spawning whitefish found in the literature. Depending on geographical locations, males first spawn from age II to VII and females first spawn from age III to X. Usually spawning females are older than spawning males. In the Loon Narrows area of Southern Indian Lake the youngest spawning male whitefish was VII while the youngest spawning female was VI. The average age for both mature males and females was 8.8 years; however, the predominant year class for the males was VIII and for the females IX (Figure 2).

The smallest mature fish found at Loon Narrows were 340-349 mm long (Table 2). These are larger than fish from Lac La Ronge, Great Slave Lake, some areas of Lake Superior and some Maine lakes but smaller than Lake Michigan, Lake Ontario, Lake Huron and some areas of Lake Superior (Table 2).

Table 2 indicates the irregular percentages of mature males and females that occur in the different size ranges. This is difficult to reconcile but could indicate that some fish do not spawn every year. A similar situation has been reported by Kennedy (1953) for Great Slave Lake and Qadri (1955) for Lac La Ronge.

4.1.4. Fecundity:

The egg counts from the 42 ovaries examined averaged 28,652

Table 1. Summary of the ages and lengths of the youngest and smallest mature whitefish from from various areas.

Author	Location	Minimum age to Maturity		Minimum length to Maturity	
		Male	Female	Male	Female
Mraz, 1964	Lake Michigan	II	III	373 mm	424
Bjorklund, 1953	Montana	II	III		
Everhart, 1958	Maine	III	V		178
Cucin & Regier, 1965	Georgian Bay	III	III	394	424
Kennedy, 1953	Great Slave	IV	VIII		307
Hart, 1930	Lake Ontario	V	V?	356	356
Qadri, 1955	Lac La Ronge			208	183
Edsall, 1960	Lake Superior (Michigan)	VII	X	297	310
Dryer	Lake Superior (Minnesota)	V	V	362-372	400-410

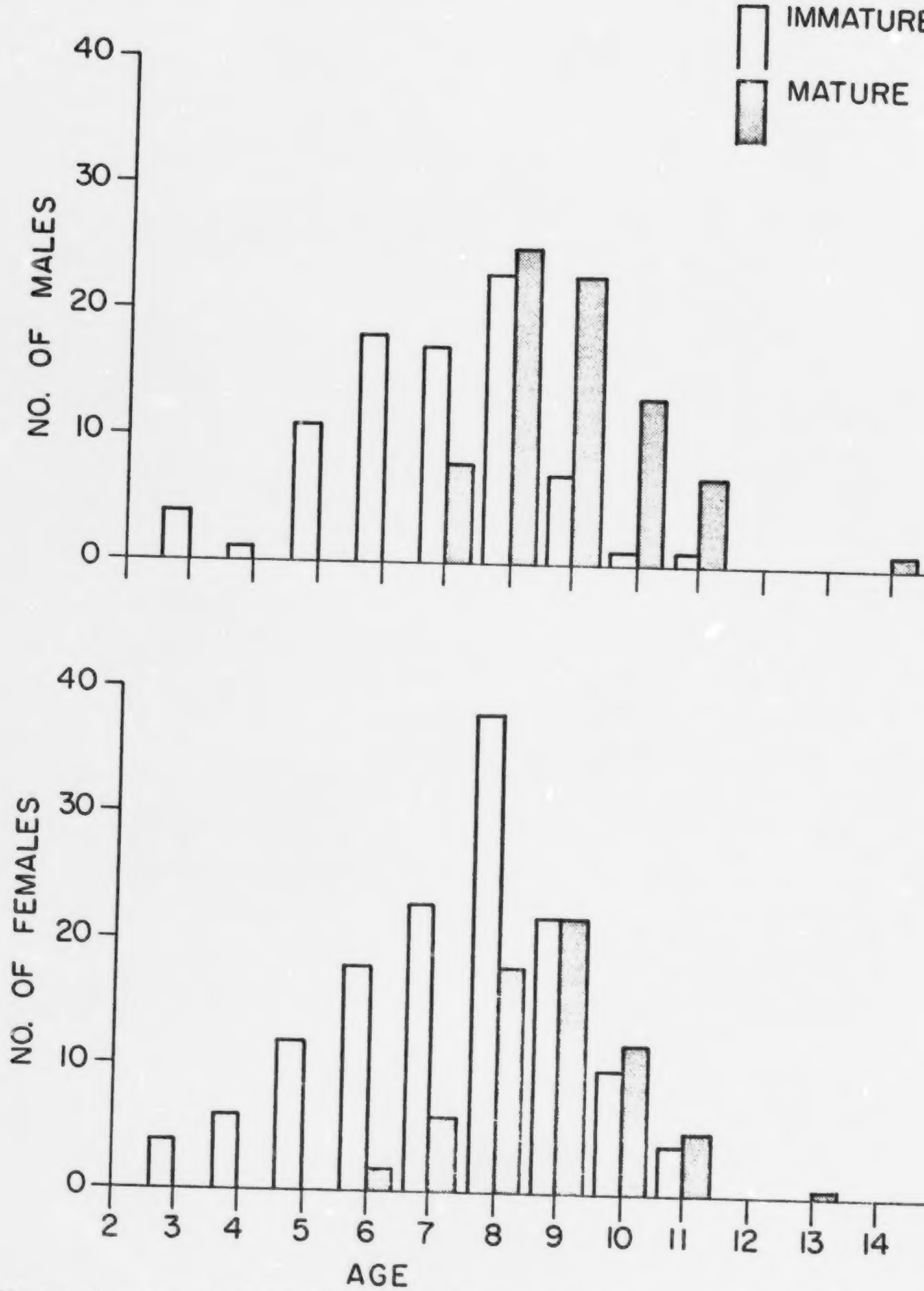


Figure 2. Age distribution of male and female whitefish netted during the 1972 whitefish spawning survey.

Table 2. Length distribution of spawning whitefish at Loon Narrows during the fall of 1972.

Length Classes	Total netted Male	Total netted Female	% mature males (number mature)	% mature females (number mature)
330-339	12	9		
340-349	19	15	6 (1)	
350-359	24	20	5 (1)	5 (1)
360-369	22	14	7 (1)	25 (6)
370-379	26	24	33 (8)	32 (7)
380-389	36	35	40 (14)	38 (10)
390-399	43	43	28 (12)	56 (20)
400-409	41	54	46 (25)	58 (25)
410-419	27	48	58 (28)	83 (34)
420-429	21	40	58 (23)	74 (20)
430-439	13	22	59 (13)	90 (19)
440-449	11	15	67 (10)	77 (10)
450-459	6	5	40 (2)	73 (8)
460-469	5	6	17 (1)	67 (4)
470-479	2	9	78 (7)	
480-489	3	4	25 (1)	50 (1)
490-499	4	3	67 (2)	67 (2)
500-509	2			25 (1)
530-539	1			50 (1)
560-569		1	100 (1)	100 (1)
660-669		1	100 (1)	

eggs/female and had a range of 14,175 to 58,000 eggs/female. The relationship between number of eggs per female and fork length is represented in Figure 3. The correlation coefficient for the curv was 0.30.

There was an average of 26,883 eggs/kg of body weight. Th is considerably lower than Lake Erie (Lawler, 1961) with 35,495 eggs/kg of body weight but higher than Lake Ontario, 21795 egg/kg (Christie, 1963), Lac La Ronge - 15,775-19,880 eggs/kg (Qadri, 195 and Lake Huron - 18,042 eggs/kg (Cucin and Regier 1965).

4.1.5 Description of spawning grounds:

In Lac La Ronge whitefish spawn over rocky bottom in water not more than 3 meters deep (Qadri, 1955); in Red Lake, Minnesota they spawn at 6-8 feet over gravel and in Lake Superior over sand or smooth boulders at depths of 1 to 12 fathoms (Eddy and Surber 1947). Hart (1930) describes the spawning grounds in Lake Ontario as follows:

> The bottom was found to be covered for the most part with flat stones from 5-91 cm (2 in. to 3 ft.) in size with occasional 'hard heads'. All were covered with a fine layer of fine silt... In the crevices and under stones whitefish eggs were found. They extended over a considerable range of depths but were observed most commonly at a depth of about 244 cm (8 ft.). None were observed below a depth of 457 cm (15 ft.).

These observations were made by diving and are the most detailed observations made on whitefish spawning grounds.

During the present study ripe females were taken as deep as 6.75 m (19.6 feet). The majority of the ripe females were take

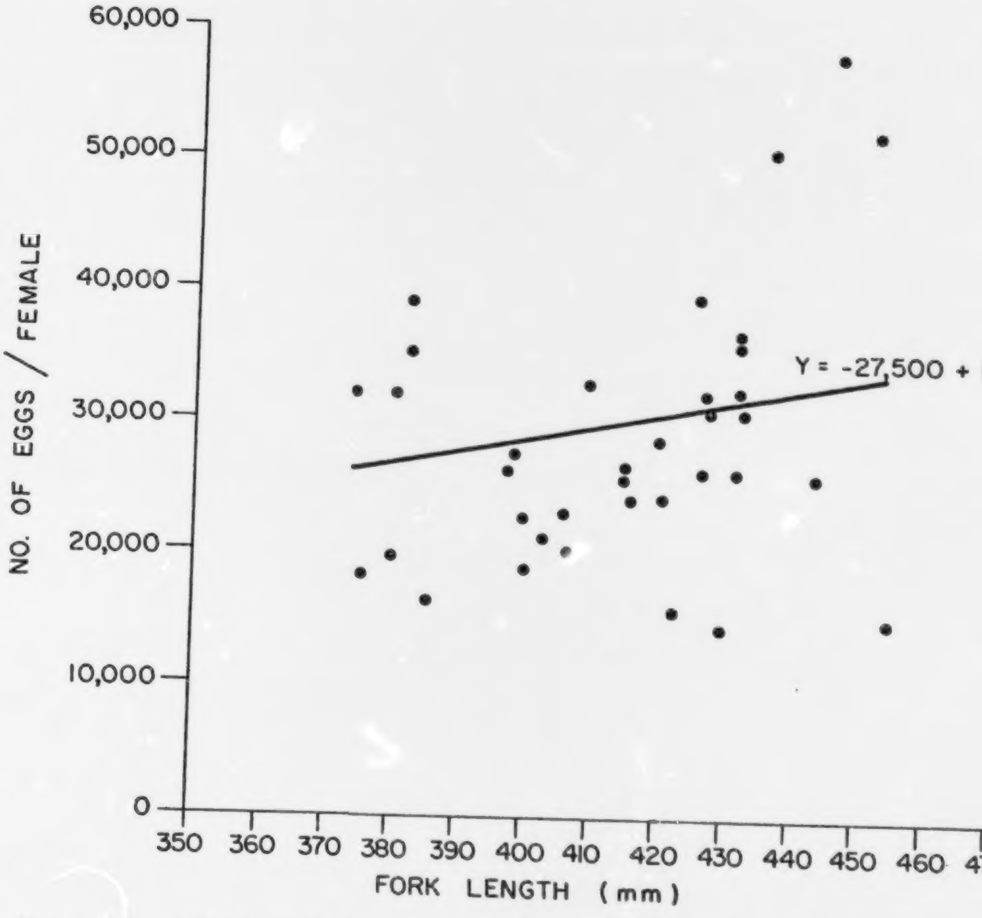


Figure 3. Relationship between number of eggs and fork length in spawning female whitefish at Loon Narrows, 1972.

at 1.5-2.5 meters (4-6.75 ft.). Here ripe females were u indicator of spawning activity because they are easier to than ripe males. Ripe females were more abundant over br and boulders and were netted only occasionally over sand substrates. Although this information is crude, whitefis to spawn in depths of 1.5 to 6.75 meters (4 to 19 ft.) an broken rocks and boulders in Southern Indian Lake. Becau substrate attempts to dredge in these areas were fruitles amounts of dredging in sand and gravel areas produced no eggs.

There are extensive areas of favourable substrate lake and under natural conditions the whitefish should hav of spawning grounds.

4.1.6 Temperature vs spawning:

Whitefish have been reported to spawn at temperat low as 33°F (0.5°C) (Red Lake, Minnesota, Eddy & Surber 1 high as 10°C (Lake Ontario, Hart 1930). In Southern India temperature seemed to play an important part in the trigg spawning activity. No ripe or spent fish were encountere water temperatures dropped from 4° to 3°C. At this point fish began appearing fairly regularly in the nets. When t temperature dropped from 3° to 2°C (October 7, 1972), the rush of spawning activity and in four days 80% of the mat netted were spent. Because of adverse weather conditions was not continued after October 10 when the water temperatu 2°C.

Hart (1930) suggests temperatures and spawning date seem to be related on Lake Ontario; he does suggest, howeve early low temperatures (4.5°C on October 26, 1925) may have the early spawning that year.

By October 10, 1972 approximately 80% of netted matu were spent and it was felt that we had observed most of the activity. The commercial fishermen, during the 1972-73 wint caught several mature female whitefish, and apparently this uncommon for the winter fishery. None of these fish were ex by the authors or staff. These fish may not have spawned du the 1972 run or they may represent members of another specie whitefish occurring in the lake which spawns in the spring. sympatric occurrence of two species of whitefish has been di by Lindsey (1963).

4.1.7 Spawning migration:

Spawning migration of lake whitefish have been repor Qadri (1968) for Lac La Ronge and Hart (1930) for Lake Ontar Southern Indian Lake dramatic changes in whitefish distribut were noted during the first weeks of September (Ayles, MS 197 which may be associated with the movement of whitefish prior spawning. The pattern seems to indicate a heavy movement of fish from the southern parts of the lake (south of Long Point to the area north of Long Point. During a similar period the was noted an increase in commercial fish landings nort Point. The fishermen suggest this is directly related spawning migration. They also suggested this area is a whitefish spawning area.

4.1.8 Hatching and early life:

From the end of October through to mid-May the of the upper six meters of water in the Loon Narrows a Southern Indian Lake is 0.5°C. According to Price (19 eggs should hatch in approximately 141 days at this te putting the hatch sometime during late February or ear This is approximately 2 1/2 to 3 months before the ice lake. The behaviour of whitefish fry under the ice ha studied.

On breakup the fry move to shallow water with vegetation (Hart 1930 and Reckahn 1970). The food dur life is mainly planktonic (Reckahn 1970). Lindstrom that young *Coregonus* sp. in Swedish reservoirs tend to tunistic feeders and do not depend on only one type o ism.

Reckahn (1970) showed the young-of-the-year w South Bay, Manitoulin Island, Lake Huron, follow the as it moves deeper in the summer months. He also sug during this stage young whitefish travel in poorly de of 2-20 fish. In Reckahn's area the 17°C isotherm us the metalimnion. In mid-August the young move into t and then gradually into deeper and colder water. He suggests the 6-8 weeks spent in the metalimnion region acts as a period of acclimation before the fish move into the cooler deeper water. There is little if any stratification on Southern Indian Lake, (Cleugh MS 1973), the shallow areas warm up very quickly in the spring and may reach temperatures of 15°C before ice is off the main lake. Whitefish eggs in the lake most likely hatch during late February or early March. No seining was done on the lake in the early summer, and no whitefish were found in shallow water when seining during July and August. From mid-July to early September the lake has water temperatures between 14 and 16°C and is homogenous throughout. This suggests the young could be randomly distributed throughout the lake. Two and three year old whitefish appeared to be randomly distributed throughout the lake (Ayles MS 1973), they were also randomly distributed in relation to depth for the months of July and August. During early September the 2 and 3-year old fish seemed to congregate in water from 20 to 40 feet deep with few individuals found in either shallower or deeper water.

4.1.9 Projected impact on spawning:

4.1.9.1 Spawning sites:

The obvious effects of the hydroelectric project on spawning will be the raising of water levels over spawning sites following impoundment and sedimentation caused by shoreline slumping and erosion during the subsequent stabilization period.

The substrates now available to whitefish will still be available at a greater depth. If the preferred depth for spawning is 8 feet and the projected rise in water level is 7-10 feet, then most of the present shoreline will be near the preferred depth. There are a few areas where large rock and cobble beaches will become available for spawning. (These areas are not extensive, however, and are usually associated with islands and partially submerged reefs).

Silting during the shoreline stabilization period will cause the most serious damage on spawning grounds. Silt will not only cover the preferred substrates but will smother any eggs deposited. Whitefish spawning is at a critical time of year with regard to sediment deposition. During the ice-free periods, sediments will be naturally cleared from the spawning areas by wave action. After freeze up, however, sediments will settle wherever they are in the water column and therefore will be deposited over spawning beds.

These problems can be avoided. The areas adjacent to present spawning grounds would have to be clear cut and burned and the over-burden removed to the bedrock, to an elevation of two feet above the new water level. Because of the extensiveness of the spawning grounds (most all the shoreline north of Long Point) this would be extremely expensive. This should be done, however, on most of the smaller islands in this area, in particular on the small islands near Missi Falls and those islands which fall between Missi Falls and Bear Narrows on the west side of the lake. Selected islands in the area of Jam Island and Sturgeon Narrows should also be included. It is felt that this would be more successful than trying to create totally new and thus foreign spawning grounds.

4.1.9.2 Migrations:

Spawning migrations of lake whitefish have been reported by other authors (Sec. 1.7) and they appear to occur in Southern Indian Lake. No information is available on the factors affecting migration orientation or the factors which initiate migrations in whitefish. They have been known to move downstream in river systems (Pollard, personal communication), or upstream (Hart 1930).

If the whitefish in Southern Indian Lake orient to anything carried by the current, the present migrations during spawning could be seriously affected by the diversion. After diversion the current will no longer flow toward the spawning grounds in the northern areas of the lake but to the south. South Bay has very little shoreline compatible with whitefish spawning at present and after diversion and the raise in lake level, it will have even less.

Because of the lack of previous work on this subject and a general lack of knowledge about fish movement in Southern Indian Lake, the above are purely speculative comments. If the migrations are affected they could cause a serious reduction in whitefish stock in future years. There are no mitigation measures that could cope with such a situation if it develops.

4.1.9.3. Early life:

Whitefish eggs on silt-free spawning grounds should not be affected by the higher water levels. Their hatching time should still be during late February to early march and early (before breakup) fry development should follow pre-diversion patterns.

The distribution patterns of 1, 2 and 3-year whitefish suggest that diversion will have little affect on them unless their main food organisms (*Amphipods*, *Spheriads* and *Gastropods*) are affected.

No realistic mitigation measures could be suggested to lessen the impacts described above.

4.2. WALLEYE SPAWNING

4.2.1. Introduction:

The walleye (*Stizostedion vitreum vitreum*) is prized highly as a sport and commercial fish. In Manitoba it ranks with lake trout and northern pike as a sport fish and demands the second highest prices as a commercial species (the highest prices are paid for sturgeon). The above are reasons enough for the numerous studies which have been done on walleye in the U.S.A. and southern Canada. In northern Canada walleye have been studied by Rawson (1957) on Lac La Ronge, Bidgood (1967) on Lake Athabasca and Derback (1947) on Heming Lake, Manitoba. Papers dealing in detail with spawning have been prepared by Ellis and Giles (1965) and Johnson (1961).

The excellent background work and its application to our present study, has made our ability to predict the impact of the project on walleye spawning far less difficult.

4.2.2 Methods & Study Areas:

There were three phases to the walleye spawning study conducted during the spring of 1973: a detailed study of two spawning runs on the McBride River and the Muskwesi River, and a synoptic Helicopter survey of 35 major tributaries of Southern Indian Lake.

The McBride River walleye run was studied from May 22 to May 29, 1973. The McBride River, drainage area 401 sq miles with an average discharge of 270 cfs, is a tributary of the Barrington River which flows into Opachuanau Lake. When the crew arrived at the river (May 21, 1973) it was free of ice and the water temperature was 10°C. At this time the major portions of Southern Indian and Opachuanau Lakes still had ice cover.

The run was sampled by the use of gill nets set in the river, both above and below the first two sets of rapids (Plates 5 and 6 and Figure 4). Only single nets (50 yd x 4 ft) were set at a station because of the size of the area. The meshes varied from 2 3/4 to 4 1/4 in stretch mesh. Early in the survey the smaller meshes were used to make sure fish were netting from all size ranges. During the latter part only 3 3/4 and 4 1/4 stretch mesh was used. The station characteristics and mesh sizes are listed in Appendix II.

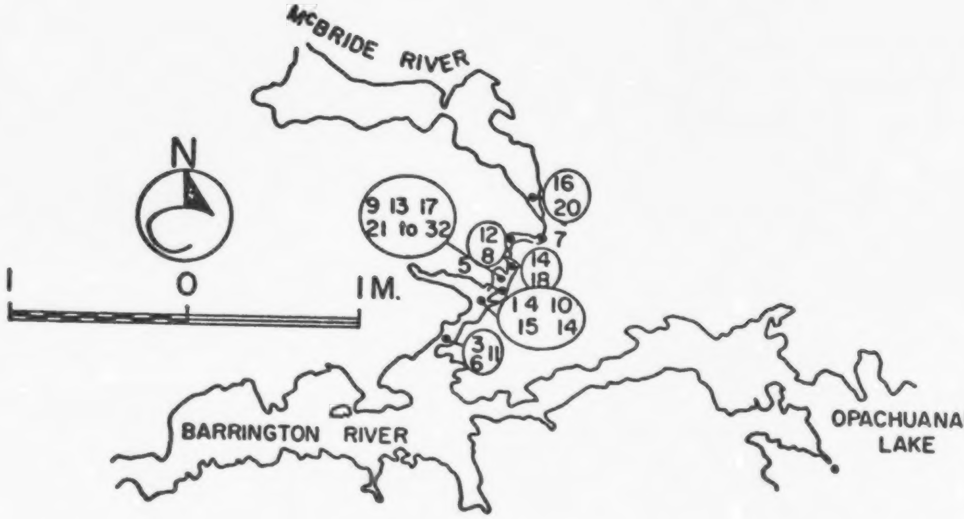
All walleye were sampled for length, weight, sex and state of maturity. Scale samples were taken from the first twenty fish from each station. The age of the fish were subsequently determined by counting scale annuli. Ovaries were taken for all mature females and preserved in 70% isobutyl alcohol. The number of eggs per female were determined volumetrically.

Nets were set mainly in the river below the first rapids but some effort was put on the study between the two rapids and in the lake above the second rapids. Although these sets provided interesting data, the time involved in reaching the nets and the shortness of the run prevented extensive fishing in the latter areas.

At 20:00 hrs on May 27 a new 3 3/4 inch stretch mesh net was set just downstream from the first rapids and attached to the

Plate 5. The lower rapids on the McBride River, believed to be the site of the majority of the walleye spawning. The river is about 150 feet wide at this point, the average flow in the river is near 200 cfs.

Plate 6. The second rapids on the McBride River.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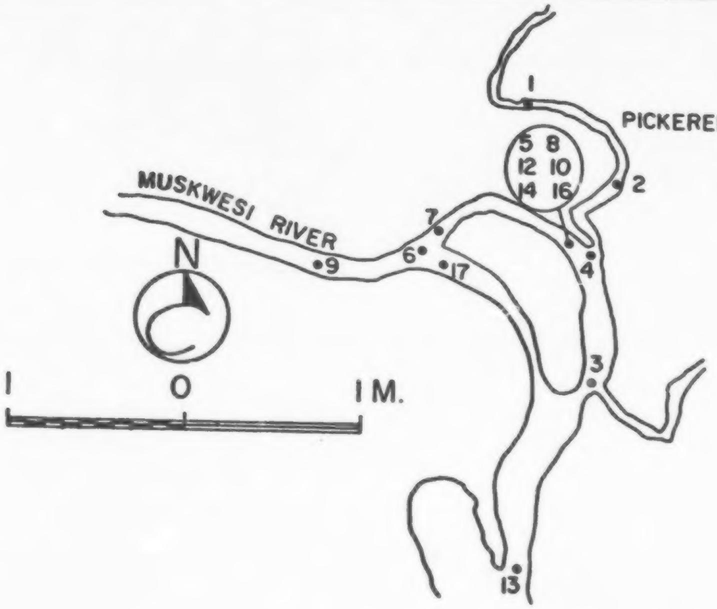
BARRINGTON RIVER
OPACHUANAU LAKE

McBRIDE RIVER,
WALLEYE SPAWNING SURVEY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MUSKWESI RIVER
WALLEYE SPAWNING SURVEY

Figure 4. The location of the net sets during the walleye spawning studies at the McBride and Muskwesi Rivers, Southern Indian Lake, May and June 1973.

west shore of the river. This net was cleaned of fish every 4 hours until 20:00 hrs on May 29, giving continuous data for a 48 hr cycle. Similar sampling procedures were followed for these fish.

The Muskwesi River, drainage area 909 sq miles, average discharge of 613 cfs, flows into the extreme northwest end of Southern Indian Lake. On June 1, 1973 a similar survey to that described above was initiated on this river. The net sets, mesh sizes, etc., are described in Appendix III. Unfortunately the program on the Muskwesi was initiated too late in the season and very few mature walleye were netted. For this reason the 48 hr set cleaned every 4 hours was not done. For the walleye netted the information and samples collected were the same as on the McBride survey.

A synoptic survey of suspected walleye spawning streams was conducted from May 22 to June 3, 1973 by helicopter. A total of 36 streams were fished for one night with a 4 1/4" stretch mes net. The streams were numbers 1, 4, 5B, 7, 11, 12, 19, 21, 23, 3 42, 44, 45, 48, 52, 54, 58, 61, 63, 73, 76, 80, 91, 91B, 92, 97, 99, 101, 105, 106A, 106A1, 107, 108, 109, 110, 111. The location of all the above streams except 91B and 106A1 are described by Cleugh (MS 1973), 91B was a tributary of stream #91 and 106A1 (no located on the map) lies about one-quarter mile due east of 106A. The nets were set in the evening and lifted in the morning and most sets were in the water for about 18 hours (Appendix IV gives the details of the sets). All walleye netted were sampled in the same manner as for the McBride and Muskwesi River surveys. The pike and sauger caught during all 3 surveys were examined for sex state of maturity. The numbers of all other species netted were noted. Daily observations were made at all stations for the presence of walleye in riffle areas. Four categories were used to describe the state of maturity of female walleye.

Immature described fish whose ovaries were small and the eggs under-developed. During early spring these fish are very eas distinguished from mature or ripe fish.

Mature described females that were going to spawn during the present spawning season. Their ovaries were very large, usual an orange-pink color and the eggs were very prominent (Plate 7).

Ripe described females that, when handled, emitted eggs. If no eggs were emitted before an incision was made the females wer classified as mature.

Spent described females that had spawned and their ovaries were devoid of eggs. The ovaries had a very stretched appearance and were a pink color. Small white oocytes could be seen in these ovaries (Plate 8). At times spent females were difficult to distinguish from immature females. Three categories were used to describe the sexual condition of males.

Immature described males that would not spawn during the

Plate 7. A mature female walleye showing the large ovaries

Plate 8. A spent female walleye showing the distended ovaries

present season. The testes were small and inconspicuou

Mature described males possessing very large te They were white in color and very prominent. Mature ma usually emit spawn when handled and are very easy to di from immature fish. Male walleye may spawn several tim period of several days (Ellis & Giles, 1963), and it is difficult to differentiate between mature and ripe fish

Spent described male walleye with very stretche that did not emit milt when handled.

4.2.3 McBride River spawning run:

On arriving at the McBride River, it was found spawning run had not started. No spent females were ne May 25 (Set #9) and this most likely indicated the begi spawning. The study area offered an excellent opportuni fish movement and the weather was sunny and warm for the survey. The flow in the river was apparently low for th year and the lack of rain didn't give the opportunity to effects of a freshet on fish movement and spawning. Pro the max-min. thermometer prevented the obtaining of accu temperatures.

4.2.3.1 Spawning vs temperature:

Rawson (1957) found the spawning run for walleye Ronge began at water temperature between 4.4° and 5.6°C most spawning activity occurred at temperatures between

Plate 9. The testes of a mature male walleye.

At these temperatures (in rivers) Lac La Ronge still had ice cover. Bidgood (1967) found the majority of the females on the Maybelle River (draining into Lake Athabasca via Richardson Lake) were spent at water temperatures of 9°C. Here, too, there was still ice cover on both Richardson Lake and Lake Athabasca. Ellis and Giles (1965) reported spawning occurred between the temperatures of 44 to 55°F (6.6 to 12.7°C) in the Falcon Lake area of Manitoba. Dirback (1947) found walleye eggs in Northwest Creek (Heming Lake area of Manitoba) where the water temperature was 43°F (6.1°C) but spawning activity stopped when the temperatures dropped to 41°F (5°C).

The water temperature in the McBride River on May 22 was 12°C. On May 25 when the first spent female was netted it was also 12°C. It appeared from the netting data and observation of the riffles that few walleye were entering the fast water before this date. If spawning did begin at water temperatures near 12°C it is considerably warmer than the temperatures reported from other areas. As mentioned on arrival, walleye were very common below the first rapids so the run was well under way and there was still considerable ice cover on the lake. It is also possible that low water tended to retard the run. Spawning was still in progress when we left the area with the water temperature at 17°C.

4.2.3.2 Age and length composition:

Scale samples were taken from 431 walleye from the McBride River. The age distribution of these fish is shown in Figure 5.

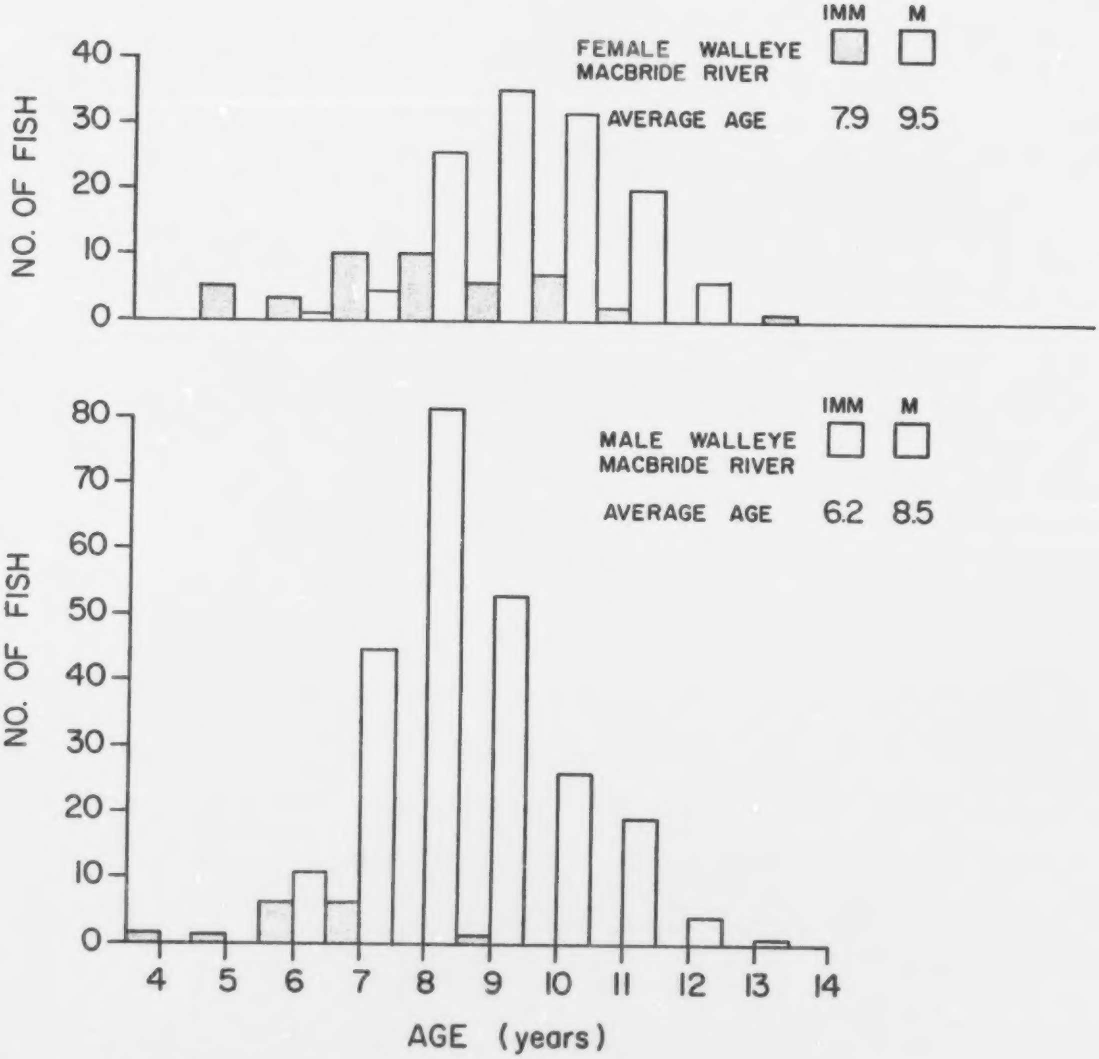


Figure 5. Age distribution of male and female walleye netted at McBride River, 1973.

The average age of the mature females was 9.5 years and the youngest mature female was VI+ with VIII+, IX+ and X+ predominant. There were immature females found in every age class up to XI+, only one immature male was found over VII+. The average age for mature males was 8.5 years and the youngest mature individuals being VI+ with VII+, VIII+ and IX+ predominant.

The average length for mature females was 42.9 cm and for mature males 40.1 cm. The females length distribution were not closely grouped and were generally larger than the males (Figure 6). This was also noted by Smith and Phyca (1961) in the Red Lakes, Minnesota. Table 3 summarizes the minimum ages and lengths of mature walleye found in the literature.

Fewer immature fish were netted with the walleye spawning run than with the whitefish, and more of the immature fish were females than males. Carlander (1945) noted a similar situation in the females on Lake of the Woods and goes on to question whether these large immature females "...skip spawning seasons, are immature or are sterile". Deason (1933) also reports large immature female walleye in Lake Erie. It is not unlikely that both female walleye and whitefish in Southern Indian Lake skip spawning seasons, however, more work on this problem is needed before a firm conclusion can be reached.

Smith and Pycha (1961) point out that because the females are substantially larger than the males they are vulnerable to the

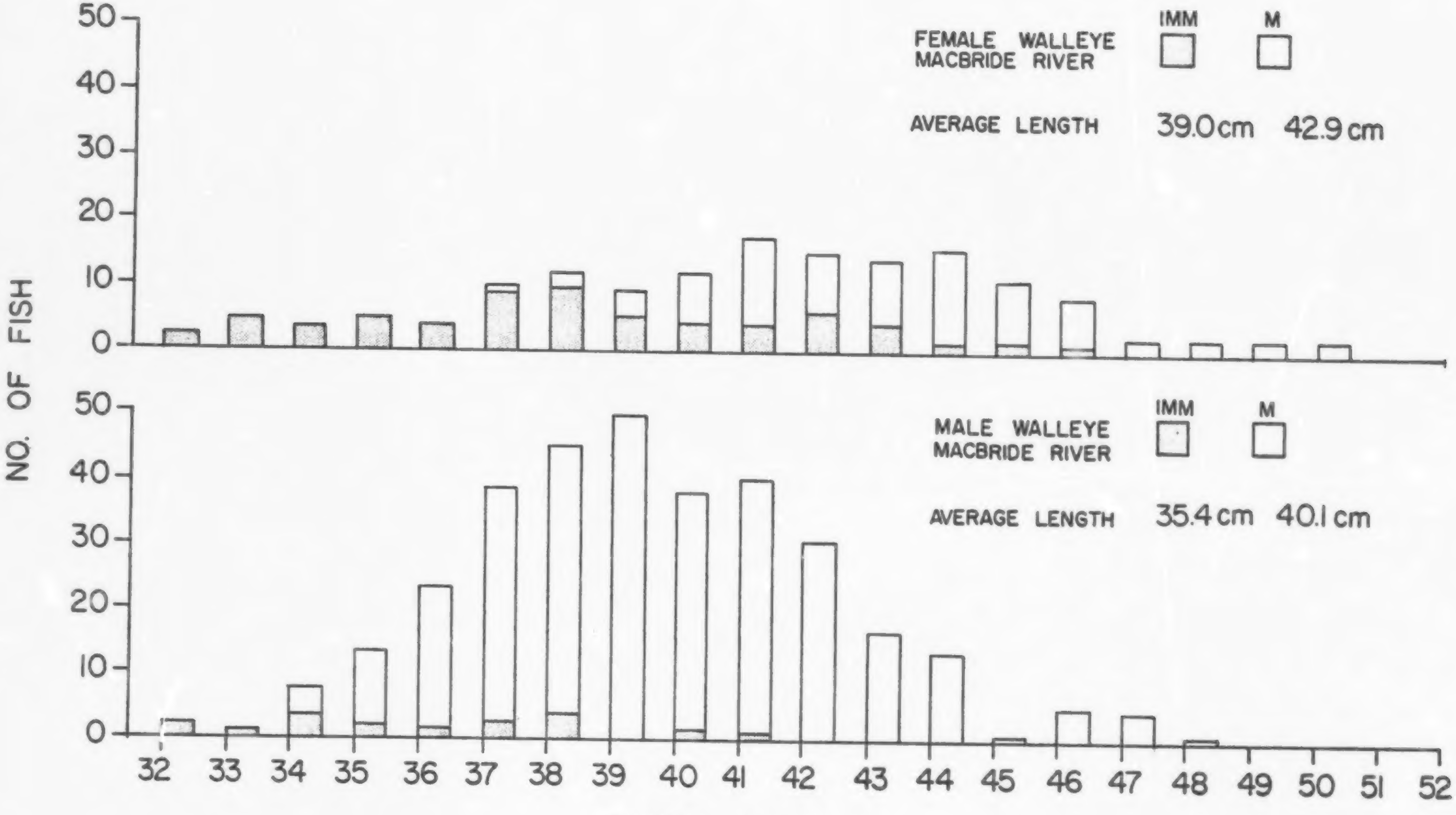


Figure 6. Length distribution of male and female walleye netted at the McBride River, 1973.

Table 3. The minimum size and age to maturity for male and female walleye as found in the literature.

Author	Area	Sex	Minimum Age	Minimum fork length	Predominant ages
Rawson (1954)	Lac La Ronge Sask.	male	5	-	8-10 years
		female	5	-	8-10 years
Carlander (1945)	Lake of the Woods, Minn.	male	-	250-300 mm	4 years
		female	-	333 mm	5-6 years
Smith & Pycha (1961)	Red Lakes, Minn.	male	-	11.2 in,(284mm)	3&4 years
		female	-	12.5 in,(318mm)	6-7 years
Southern Indian Lake (McBride River)		male	6	330-339 mm	7-9 years
		female	6	370-379 mm	8-10 years

commercial fishery at a much earlier age (before maturity on the Red Lakes). This could have a detrimental effect on walleye production. On Southern Indian Lake and Opachunau Lakes the walleye taken in experimental 4 1/2 inch stretch mesh gill nets averaged 16.5 inches fork length (41.9 cm). This would tend to crop mature females at a higher rate than mature males, but it would crop at a fork length well above the minimum size at maturity and should not adversely affect the spawning population.

4.2.3.3 Movement cycles:

Walleye movement associated with spawning runs is well documented. Forney (1963) found that walleye in Onieda Lake, New York homed to a particular stream for spawning and there was evidence to suggest spawning populations from the same creek moved together during the summer. Crowe (1962) showed walleye in the northern part of Lake Michigan returned to the same spawning areas year after year. Rawson (1956) reported that males return to the lake from the spawning grounds later than females and may remain in the stream from 3-6 weeks. He also found that fish taken by gill nets in Lac La Ronge during June were immature. The walleye in Lac La Ronge tended to move in response to the availability of food rather than to avoid extreme temperatures. Spawning populations in Lac La Ronge tend to mingle in the open lake but separate again during the spawning runs. Bidgood (1967) found walleye were moving considerable distances (74-86 miles) from the spawning grounds to the summer habitat on Lake Athabasca. Olson and Scidmore (1962) studying homing in walleye in Many Point Lake, Minnesota showed there was a direct correlation between the number of marked fish returning to a stream and the volume of stream flow and that homing behavior is more developed in some individuals than others.

Pre and post-spawning walleye movement as described in the literature can be summarized as follows. The male walleye reach the spawning grounds first and remain the longest. The females arrive shortly after the males but don't linger in the area; they tend to spawn and leave. Males may remain in the spawning area for 3-6 weeks, gradually moving back to the lake. The population during the summer (July and August) disperse throughout the lake more or less randomly.

4.2.3.3.1 Pre-spawning movement:

Our first net set produced far more males than females. It was assumed that the pre-spawning run was well underway and probably had been for several days. The sex ratio quickly dropped from 3.9:1 (Males:females) on May 23 to 2.0:1 on May 26 (Figure 7). This indicated females were moving into the area, and spawning commenced. During this period May 25 and 26, walleye were very prominent in the first rapids (Plate 10) . On May 28 and 29 the sex ratio began to rise again. This indicated females were leaving the area, most likely after they had spawned.

Although fishing effort in the lake above the second rapids

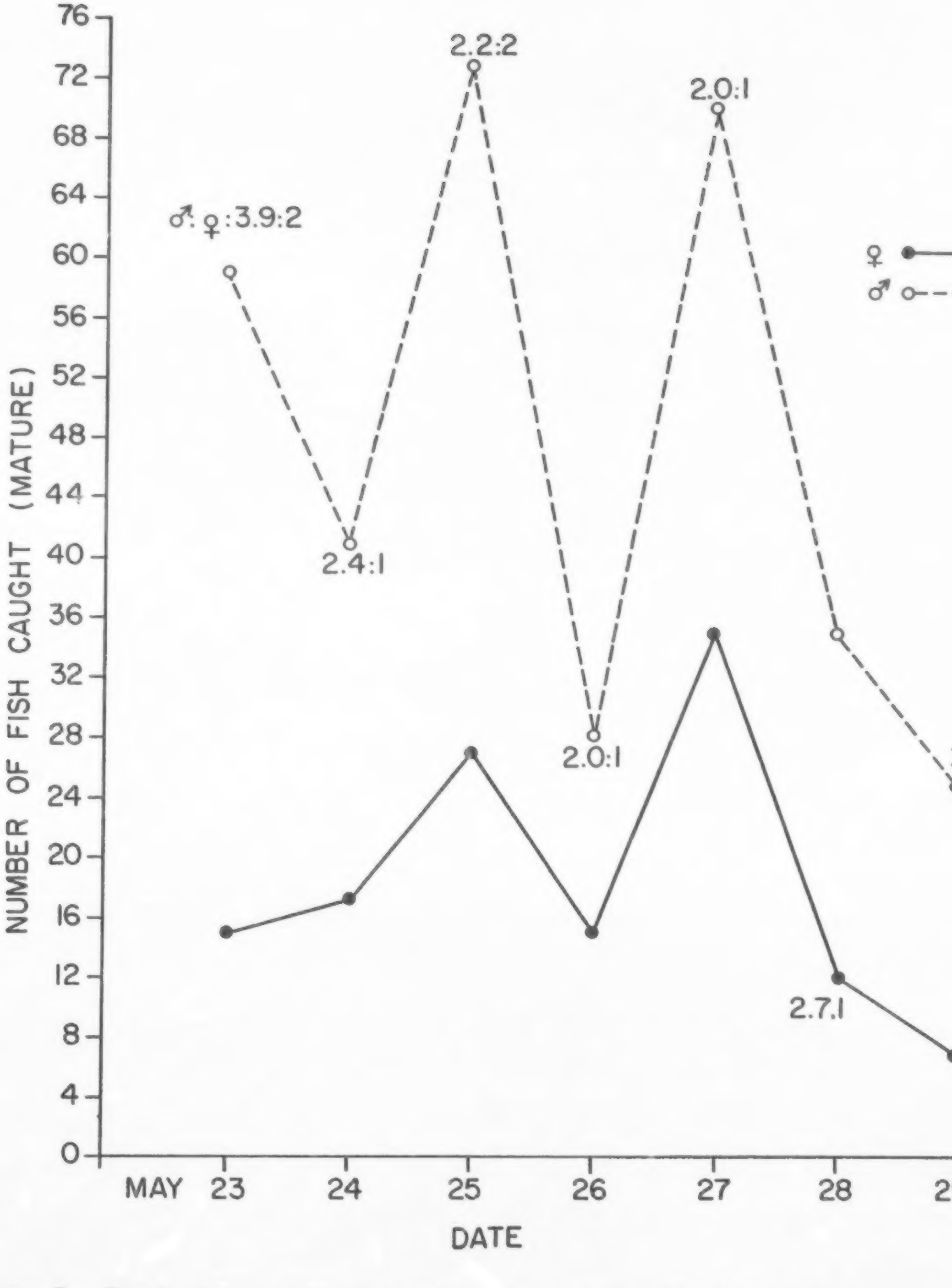


Figure 7. Total mature walleye caught and the sex ratio for each day of the spawning survey on the McBride River, 1973.

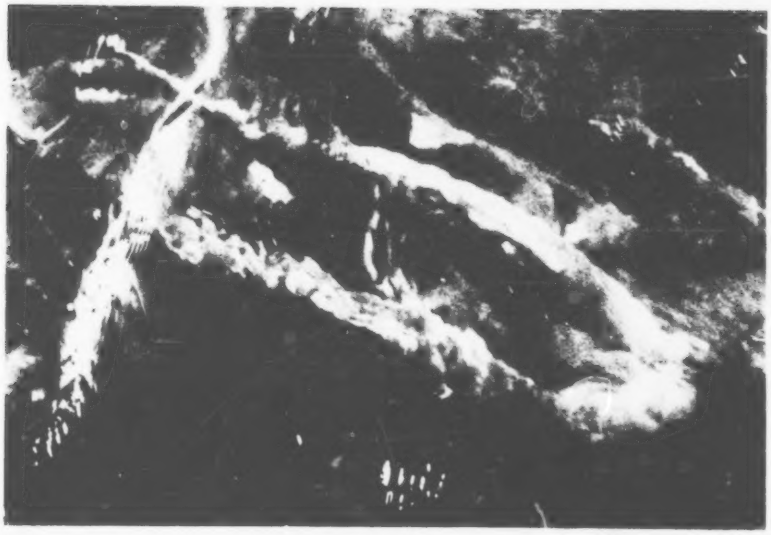


Plate 10. Walleye in the first rapids of the McBride River duri
the spawning season.

was limited (2 sets) 7 out of 10 females caught there were spent. Females may have moved upstream after spawning before they returned to the main lake. Local residents have mentioned a genera movement of walleye from upstream lakes into the main lake during July which would support the above observation.

4.2.3.3.2 Post-spawning movement:

Post-spawning movement patterns can be determined from the experimental fishing data collected on the lake during 1972 (Ayles MS 1973). In general walleye were found to be very localized duri July. At this time they were most likely just leaving the spawnin areas. During August they are more randomly distributed throughou the lake, and during September, they can be found almost anywhere on the lake in small numbers. Ayles (MS 1973) discusses this in greater detail.

4.2.3.3.3 Diurnal movement during spawning:

Figure 8 summarizes the fishing data during the 48-hour se to determine variations in movement throughout the day. The perio of highest activity is from 24:00 to 08:00 hours and very few fema were caught except during the dark hours (approximately 23:00 to 05:00 hours). The ratio of mature to immature fish is also lower during the daylight hours indicating differences in activity patter between the two groups. Ellis and Giles (1965) show spawning activity to be most intensive during dusk which would account for the higher activity during the 20:00 to 24:00 hour sets. They did litt

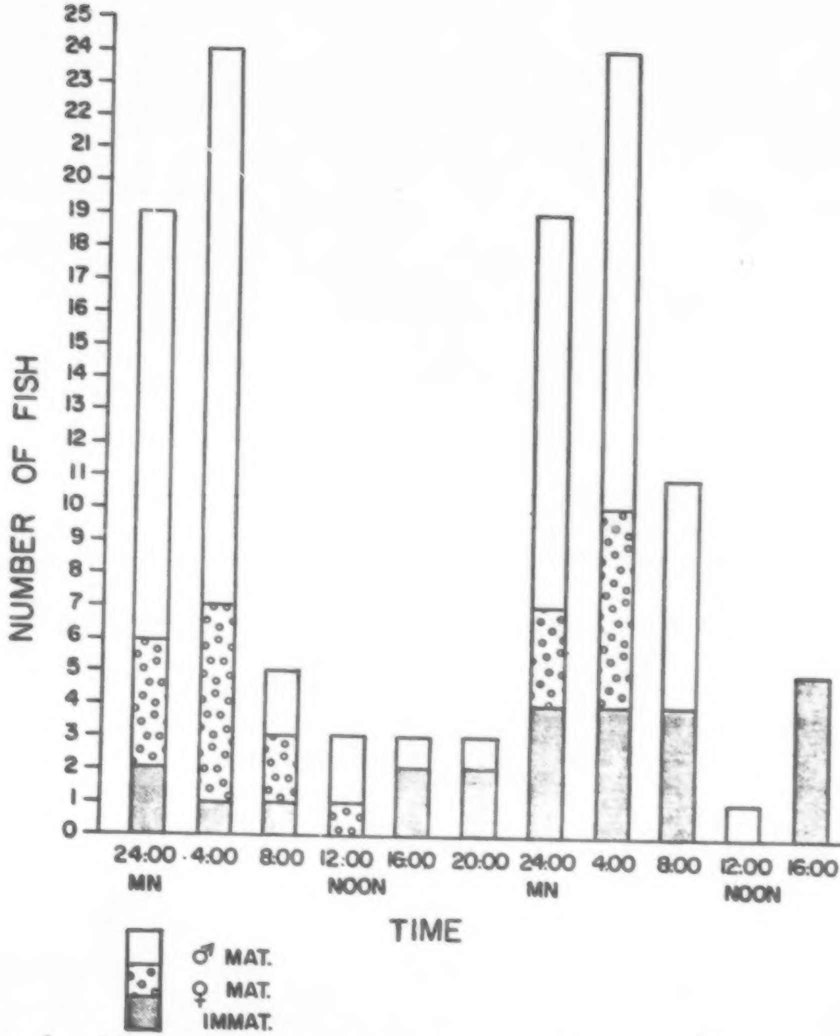


Figure 8. Fish netted during four hour periods for 48 hours or
May 27 and 28, 1973 at the McBride River, MN-midnigh

work during the hours of dawn (24:00 to 04:00 hours) during wh we also had high catches. The latter high catches could be du fish moving out of the riffle rather than upstream movement. ing the day walleye were not uncommon in the riffles but showe little movement. Some individual fish were noted to be in th same place for hours and when disturbed they would only move s distances. Derback (1947) also mentions walleye "...resting i tected bays or behind rocks in the rapids" during daylight hou

4.2.3.4 Spawning sites:

Most walleye spawning on the McBride River appeared to place in the first rapids above the lake. Nets set above the f rapids and above the second rapids yielded relatively few walle most of which were spent. There were few walleye seen during t day in the second rapids. The substrate in the rapids was cobb (6" - 2 feet in diameter) interspersed with gravel and clear of muck and organic debris. The water was from 1 to 4 feet deep. Johnson (1961) described a similar area and found high egg surv on this type of substrate (34.3% survival at the end of incubat

4.2.3.5 Fecundity:

The smallest number of eggs/female was 12,274 for a X+, 822 gm fish and the most eggs/female was 92,677 for an XI+, 490m 1673 gm fish. The average number of eggs/female was 46,634. Th was a good correlation between the number of eggs per female and weight (r = +0.65) with the number of eggs increasing with incre body weight (Figure 9).

Carlander (1945) found 35,000 - 137,000 eggs/femal
an average of 50 eggs/gm of body weight on Lake of the Woo
Minnesota.

4.2.4 Muskwesi River spawning run:

The June 1, 1973 water temperature on the Muskwesi
was 14°C. The first day's net set caught 20 walleye 85% o
were spent. The entire study only netted 64 walleye, 88%
were spent (Figure 10). The number of fish netted per day
as the study progressed.

It is felt that the major walleye run on the Muskw
occurred at about the same time as the run on the McBride.
fish caught during our study were mainly the spent individu
gradually moving back to the lake. Although the river was
of ice there was still ice on the northern areas of Souther
Indian Lake on June 9, 1973

The average age of the mature female walleye on the
River was 9.6 years and the average length 432 mm. The ave
the mature males was 10.1 years and the average length 426
The average age of the males was believed to be biased beca
were not getting a representative sample of the total male
lation. The sex ratio, males:females for the study was 0.6
would indicate the males had not begun their post-spawning
stream movement.

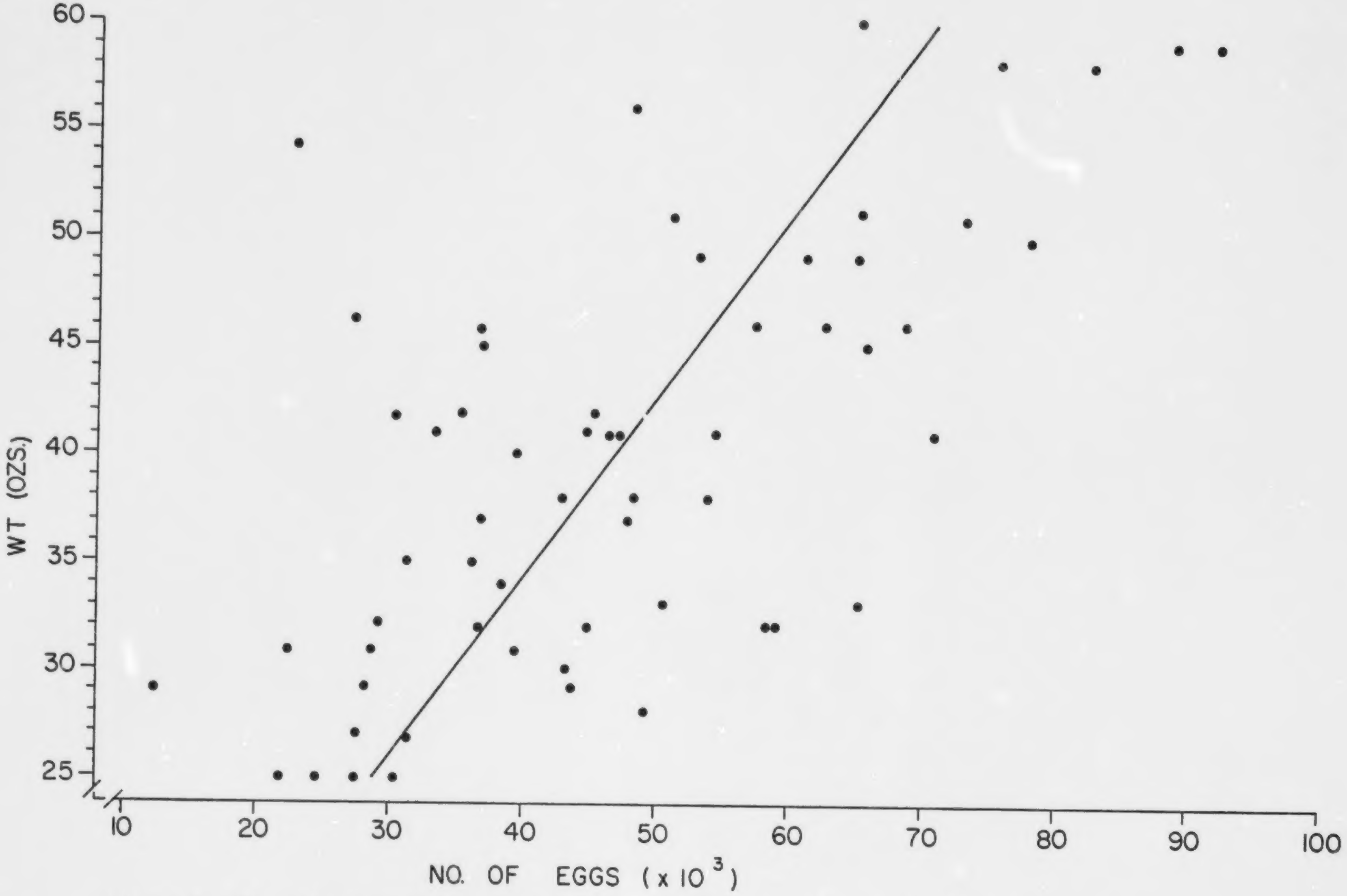


Figure 9. The relationship between fork length and number of eggs in mature females from the McBride River, 1973.

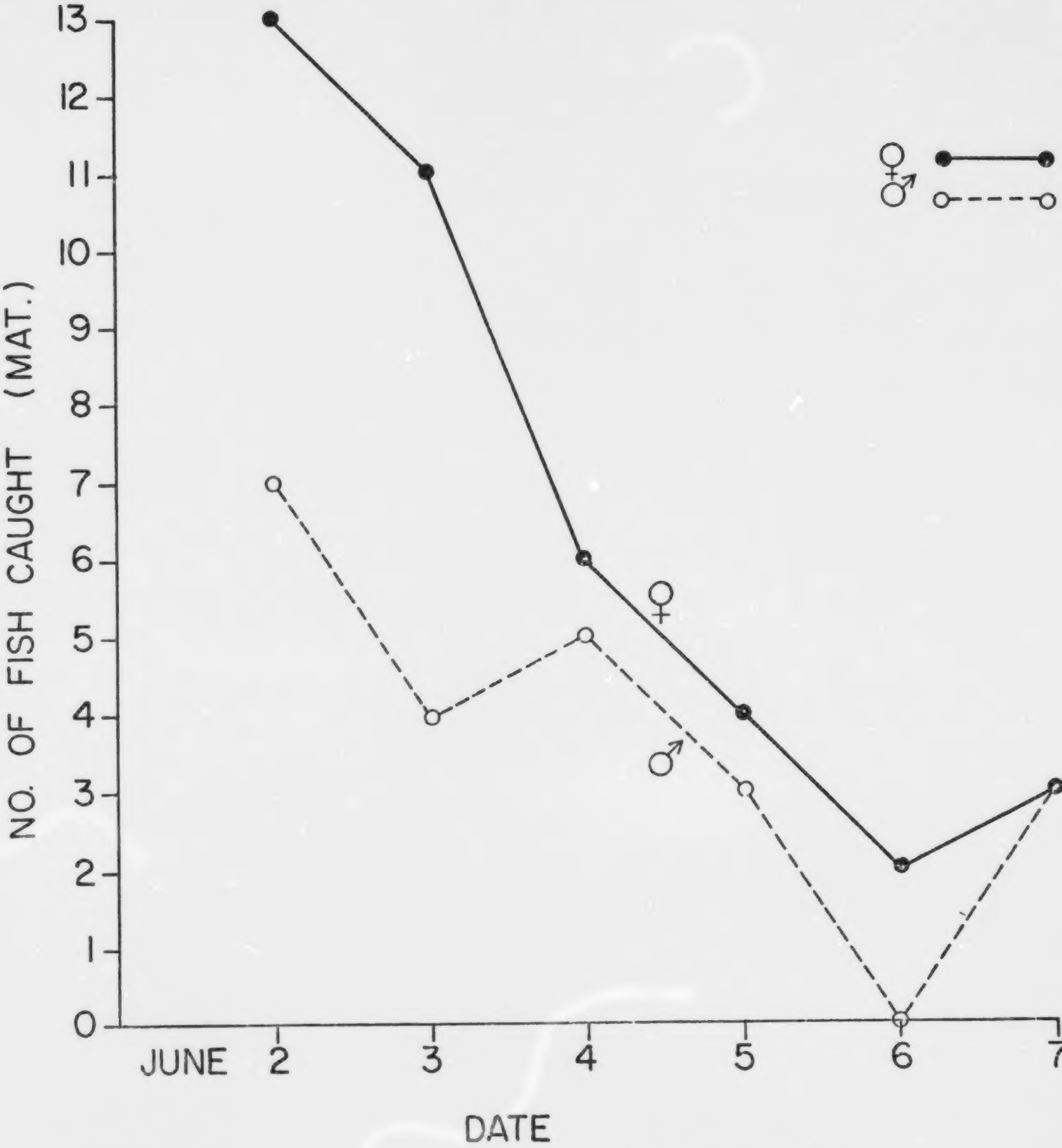


Figure 10. Daily number of walleye caught during the Muskwesi River walleye spawning study, 1973.

Only three females with intact ovaries were netted giving little indication of the fecundity.

4.2.5 Synoptic survey:

There are few large rivers entering Southern Indian Lake and Opachuanau Lake excluding the Churchill River. Large walleye runs were found in streams 4, 5, 11, 48, 63, 76, 97, 99 and in tributaries of the Churchill just upstream of Opachuanau Lake, streams 1 and 111. Excluding the Churchill River, streams 5, 48, 63 and 79 are four of the five largest tributaries. Tributaries 4, 11, 97 and 99 are considerably smaller. More data on these streams can be found in Cleugh (MS 1973). Figure 11 shows all streams fished.

The survey pinpointed eight major spawning areas. They are the Barrington River (including the McBride River), the Barlow Lake drainage, the McLeod Lake drainage, the Muskwesi River, the Waddie River, Sandhill Bay, the Cousins Lake drainage and the tributaries of the Churchill River. It was also thought that streams 19, 20 and 21 could have very high walleye spawning potential but this was not born out by the inspection. All the streams where concentrations of walleye were found have not only suitable substrate and flows for spawning (described in Sec. 2.3.4) but they also have lakes in their drainage. It is not fully understood what part, if any, these lakes play in the spawning process.

Walleye at all locations, excepting stream 1, appear to

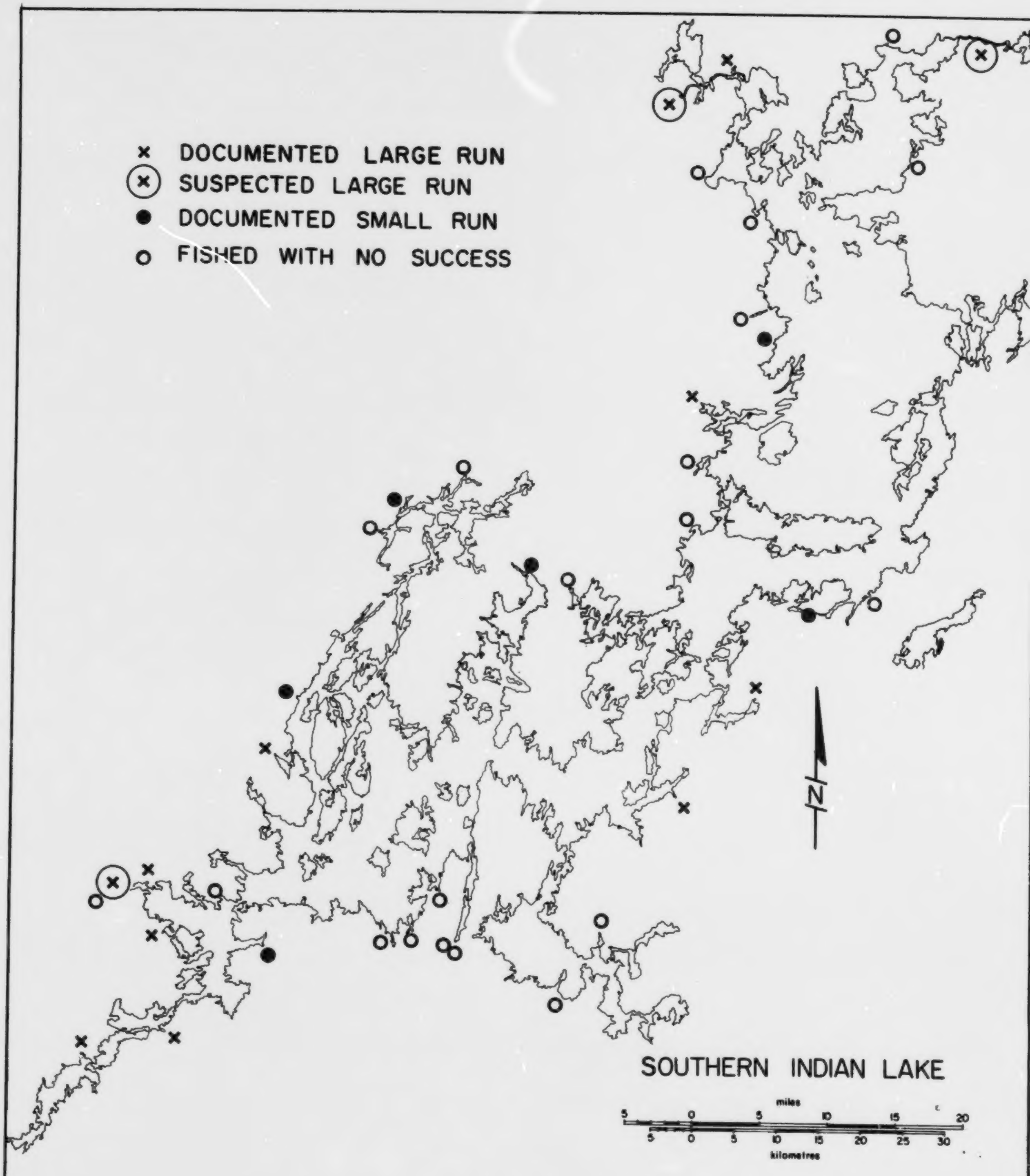

× DOCUMENTED LARGE RUN
⊗ SUSPECTED LARGE RUN
● DOCUMENTED SMALL RUN
○ FISHED WITH NO SUCCESS
N
SOUTHERN INDIAN LAKE
miles
5 0 5 10 15 20
5 0 5 10 15 20 25 30
kilometres

Figure 11. Location of the streams fished and extent of the run during the synoptic survey of walleye spawning, Southern Indian Lake, 1973.

have similar growth characteristics and mature at similar ages and sizes. At stream 1 the average age of mature males was 6.7 years and the average length was 394 mm (n = 43). The average age of the mature females was 7.8 years and the average length was 418 mm. Average length of both males and females was substantially lower than the fish from the McBride River. This may indicate a population of Churchill River walleye that do not mix with the Opachuanau fish, or heavier cropping of this population than the McBride River population. The latter is unlikely because the females would be cropped more heavily than males thus lowering the females average age more than the males. Another reason to reject cropping is that in stream 111 which is nearer Opachuanau Lake the average length and ages of both males and females are very close to the McBride River and with no commercial fishery on the river it seems unlikely these two populations would be cropped at different rates.

4.2.6 Early life:

Walleye eggs hatch in 26 days at 40°F, 21 days at 50 to 55°F and in 7 days at an average of 57°F (Niemuth, Churchill and Wirth, 1959) in Wisconsin. On Southern Indian Lake the incubation period is probably from 10-15 days depending on the water temperatures. On Oneida Lake, New York, the walleye fry spend their first 4 to 6 weeks in a pelagic existence concentrated near the surface of protected bays (Houde, 1967). There is little information available on the timing, etc. of walleye fry leaving the streams.

Oneida Lake walleye from 7-10 mm long consumed 85-91% *copepods*; and, from 13-24 mm, the diet included *copepods*, *cladocerans* and fish in similar proportions (Houde loc. cit.). Lyashenko (1961) and Boiko (1964) reported starvation of young-of-the-year in Soviet reservoirs when food became scarce. It is felt generally that zooplankton abundance could be a limiting factor in the survival of walleye. In other cases, walleye fry depend heavily on yellow perch fry for food (Smith and Pycha 1960). Any situation that would affect either zooplankton or fish fry abundance could affect the survival of walleye fry.

4.2.7 Impact and Mitigation:

Little is documented on the effects of impoundment on river spawning walleye populations. The impact predicted below is based solely on the findings of this study.

4.2.7.1 Spawning sites:

It appears that on Southern Indian Lake and Opachuanau Lake walleye are spawning in the first set of rapids above the lakes. If this is the general case then almost all spawning areas will be flooded after impoundment. It is still likely walleye will home on these streams and they should still spawn. The location of the new spawning grounds will have a strong effect on egg survival. If they proceed upstream, after impoundment, to the next rapids or the next similar spawning area, egg survival will remain at a level similar to pre-impoundment. If, however, they continue to spawn in the present spawning areas, there will be a significant reduction in egg survival. This reduction would be caused by changes in substrate characteristics on the former spawning beds caused by silting. Johnson (1961) outlines the differences in egg survival on different substrates with the poorest survival on soft muck and best on gravel and rubble. Lake spawning walleye populations have not been found in these lakes, and it is highly unlikely that river spawning fish would develop lake spawning habits.

4.2.7.2 Movement:

The homing of walleye to a particular stream has been well documented (Sec. 4.2.3.3). Post-impoundment conditions should not change these movements. In the southern part of the lake the flow will be in the same direction and there should be few factors changed that would affect homing. In the northern regions, the flows during the spawning run may or may not be changed. Irregardless, walleye begin accumulating near the stream mouths in late winter (personal communication with local people) and it appears unlikely that they will not be able to detect a specific stimuli (most likely the water from a specific river). In South Bay the increased flows could possibly affect movement but the lack of large spawning populations in the area will lessen the impact on the lake as a whole.

4.2.7.3 Mitigation:

One worthwhile mitigation measure would be to clear and burn the shorelines near the 8 rivers presently known to be used for spawning to two feet above the new high water level. On the rivers entering the Churchill River and those entering Opachuanau Lake, this would mean very limited clearing (2-6 feet in elevation). On Southern Indian Lake tributaries the clearing would have to be more extensive. These rivers should be cleared from 100 yards downstream of the foot of the present rapids to the point where the 2 feet + new high water level contour intersects the rivers. This would lessen the chance of the blocking of the entrance of these streams by floating debris. It would also enhance the travel by boat and canoe to and from these areas (all the streams mentioned are used extensively for transportation to and from traplines).

5. COMMERCIAL FISHERY

5.1 History:

The commercial fishery on Southern Indian Lake began in the winter season of 1941-42 through the efforts of Tom Lamb. In the first years his crews was hired from The Pas and Wabowden at a rate of $75 per month. Because of the lack of experience and equipment few locals were hired during his first years of operation. Lamb's first year of operation wasn't very successful because he was flying the fish to Wabowden. In later years he began hauling frozen fish by "Cat-swing" to Wabowden or Sherridon. Lamb marketed the fish himself and never bought for an agent. He operated as many as 13 camps on Southern Indian Lake during his eleven years there (Fig. 12). Lamb's operation on Southern Indian Lake folded in 1952.

In 1943 two brothers, Billy and Murdo Clee, began buying fish on the Lake. They began to outfit the local fishermen and for a period of two years were in competition with Lamb. Their top wages were $150 per month. Until 1949 the Clee's marketed their own fish, after that they acted as buying agents for Keystone Fisheries. They still own Camp 9 near Long Point and lease it to the South Indian Lake Co-operative Fisheries Limited for 1¢/lb on all fish bought at the camp by the Co-op.

Clee's were the largest and most successful of the local

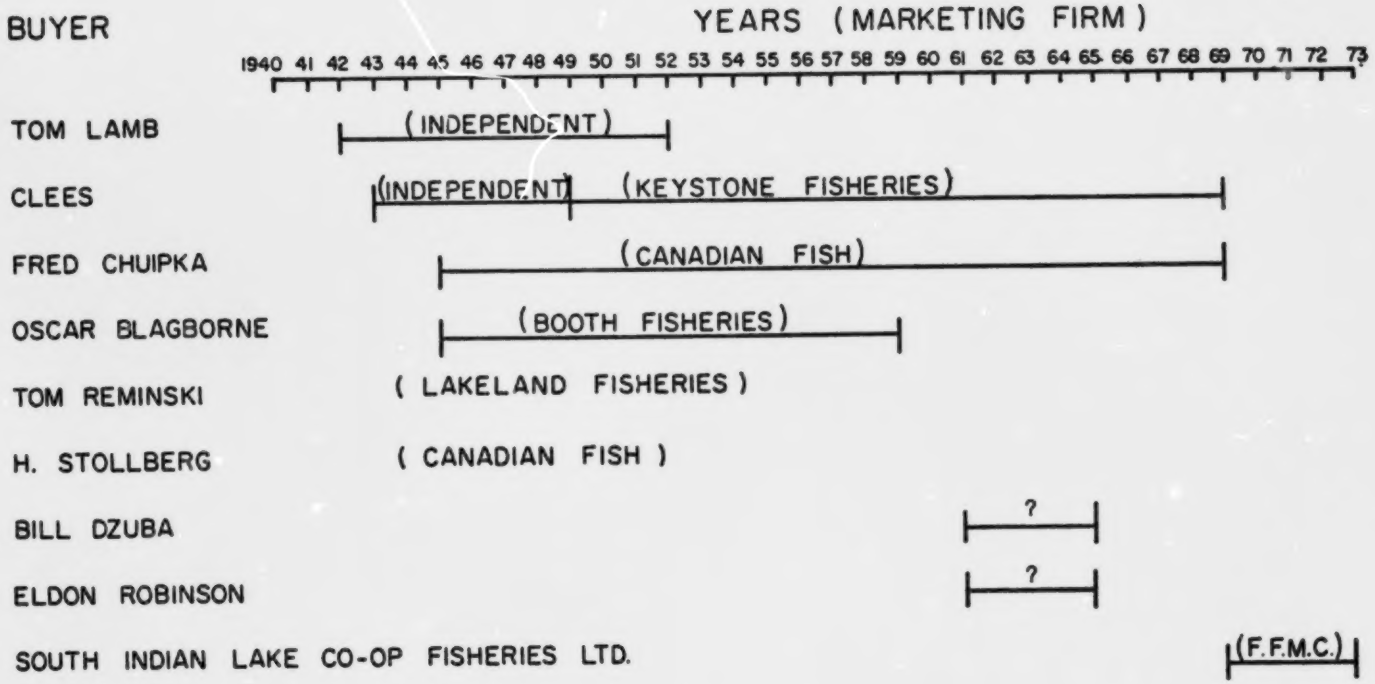


Figure 12. The past fish buyers on Southern Indian Lake, showing their approximate period of operation and their agents.

fish buyers.

Fred Chuipka started buying at Loon Narrows in 1945. Here he built a sawmill which produced the lumber for the present buildings. Chuipka concentrated his buying efforts in the north end of the lake, north of Long Point; and therefore he was not in direct competition with Lamb or the Clees. Chuipka was an outfitter as well as a buyer. He paid $150/month, plus 1¢/lb of fish, plus room and board for those working for him. He was an agent for Canadian Fish.

Oscar Blagborne also began buying fish in 1945. He had no camps on the lake and fishermen would bring their fish to South Indian Lake, where he bought them for from 3¢ to 5¢/lb. Blagborne also operated a store at the settlement which was in competition with "the Bay". He bought as an agent for Booth Fisheries until 1959.

Bill Dzuba and Eldon Robinson also bought fish in the early '60's. Their operations were short lived and were apparently operated out of camps formerly owned by Lamb and situated at Camp 7, Jam Island and Long Point. Little information was available about these two buyers.

Scattered around the lake there were several camps operated by local buyers. These men usually bought fish for one of the larger buyers on the lake. These facilities were very common on the northwest arm of the lake. Very little information is available on these facilities.

In 1969 the South Indian Lake Co-op Fisheries Limited, bought out Chuipka and leased Clee's Camp 9. They now operate facilities on the lake, Camp 3, Camp 9 and Loon Narrows. Durin the summer fish is bought at all three stations, but in winter Loon Narrows operates.

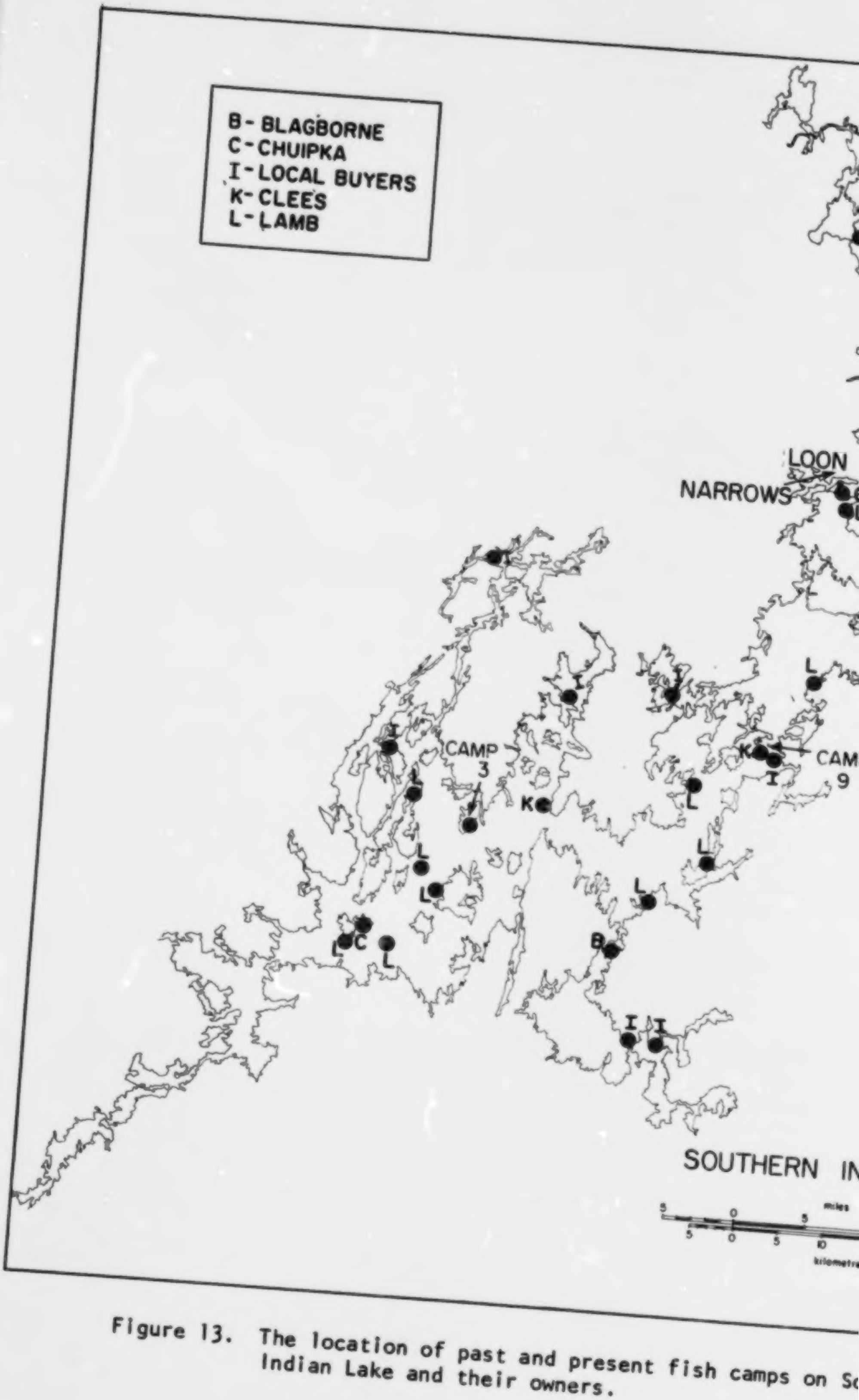
As with all northern fisheries, the most critical proble is getting the fish to market in good condition; from the beginn this has hindered the economic success of the Southern Indian La commercial fishery. Lamb found during his first few years of op ation that aircraft were too costly and he switched to "Cat-swin for transportation. This presented two problems; only frozen fi could be shipped (frozen fish bring a lower market price than fr and it could only operate during the winter. By air Lamb shippe fish to Wabowden, a distance of approximately 136 miles; by "Cat swing" he shipped to Wabowden or Sherridon (142 miles).

It is not known how other buyers shipped their fish, but it is likely to have been by "Cat-swing" at first (the '40's and early 50's), and later by Bombardier and plane. The latter meth were more expensive but allowed the fish to be shipped fresh and therefore allowed a higher market price. The Clees and Chuipka usually delivered to Lynn Lake a distance of approximately 80 mi

The summer fishery began in 1950 and, until 1972, all fi caught during the summer were flown to Lynn Lake. In summer the problem was spoilage and the time from the net to the plant was critical. With the completion of the Lynn Lake to Leaf Rapids road, the transportation costs were lowered because fish can be transported to Leaf Rapids by boat in summer and Bombardier or plane in winter and from Leaf Rapids to Lynn Lake by semi-trailer in both summer and winter.

Wabowden, Sherridon and Lynn Lake were chosen for the fis shipments because they were on rail lines which provide cheap tra portation to the southern markets. The road, presently under construction from Thompson to Leaf Rapids will provide even better transportation links with the south.

This short account of the history of the Southern Indian Lake fishery is far from complete. There are probably many people who contributed to the fishery who have been omitted. It does giv an account of the major buyers in past years and the location of their "fish-camps" on the lake (Fig. 13). A more detailed account is beyond the scope of this report.


B - BLAGBORNE
C - CHUIPKA
I - LOCAL BUYERS
K - CLEES
L - LAMB
LOON
NARROWS
CAMP 3
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9
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miles
kilometres

Figure 13. The location of past and present fish camps on So
Indian Lake and their owners.

5. 2. FISHING METHODS

5.2.1 Summer:

All commercial fishing on Southern Indian Lake is done with gill nets of 5 1/4 inch stretch mesh. Each licensed fisherman is permitted 1,500 yards of gill nets. The nets most commonly used are 100 yds long, 40 mesh deep (18 feet) and are made of 210/3 nylon twine. They have a float line with plastic floats and a lead line with 3 in x 1 1/2 in diameter split lead sinkers. When the nets are worn out, the floats and leads are removed and used on the new nets. The anchors and buoys come in many sizes and descriptions. Most often large rocks, about 20 lbs, are used for anchors and the buoys are made of wood with a mast carrying a flag. The flag, by law, must carry the fisherman's license number. Anchor lines are usually made of side line.

The nets are set from open boats, most commonly 19 ft wooden yawls, powered by outboard motors. The fishermen prefer 20 to 25 hp motors because they are economical to operate and repair. Usually two motors are used per boat. These boats seem to be an optimum length for the lake. They are economical to buy (about $700), and they are very seaworthy. Smaller boats are not used because they are more vulnerable in heavy seas, and larger boats are more expensive both to purchase and to run.

During the summer the fishermen follow a traditional pattern as they move from camp to camp on the lake. The season opens on June 1 and at this time the fishermen start fishing either at Opachuanau Lake or Camp 3. As the summer progresses they move to Camp 9 (about July 1) and from there to Loon Narrows. The Loon Narrows camp usually produces the most fish per season, but the ice is often on the lake in region 4 until mid-June. From mid-June to the end of the season on October 15 the fishermen deliver their catches to Loon Narrows. The closing of the other camps is often dependent on the amount of ice available.

Gill nets are easily relocated during the summer fishery and fishermen are less tolerant of low catch per unit of effort. Once nets are set they remain in one location until catches drop off, sometimes for weeks. The gill nets are set from the front of the boat as the motors are run in reverse, one man operates the motor while the other plays out the net. An anchor is placed on each end of a gang of nets. A gang may be up to 10 nets. In cases where large catches tend to float the nets, additional anchors are placed along the length of the nets. The major whitefish fishing grounds are usually in water of 50-70 feet. Only in the fall (during the whitefish spawning run) or if walleye are sought will nets be set near shore in shallow water. In the deeper water there also seems to be fewer coarse fish. Once set the nets are lifted every day.

A typical day begins by getting several boxes of ice to ice the catch. Then the trip (1-30 miles) is made to the nets (Plate 11). The nets are cleaned of fish (picked) by passing them over the gunwhales of the boat (Plate 12). They are only completely removed from the water when they are to be reset. As fish are removed from the net they are dressed (Plate 13). The offal is placed in a tub on board and when the dressing is completed the offal is dumped into the lake. Coarse fish are usually killed and thrown into the lake (smoked longnose sucker is a delicacy and large specimens of this species are often kept). The dressed fish are packed in wooden fish boxes and iced. At this stage they are usually packed with 80 lbs of fish and 20 lbs of ice to a box. When all the nets are picked the fishermen head back to the camp. Dressing is usually finished on the return trip. At camp the fish are moved to the fishhouse (Plate 14) where they are sorted (for size) and weighed. The fishermen will then wash their boxes and their boat in preparation for the next day. There are usually two men per boat and often two licensed fishermen will fish from one boat picking up to 30 nets a day.

5.2.2 Winter:

Winter fishing methods are quite different from summer methods. The licensed fishermen are still limited to 1,500 yds of gill net and the nets used are the same as those described above, but methods of setting and lifting nets and bringing fish to the fish camp are different.

Plate 11. Commercial fishermen on Southern Indian Lake ready to leave for the nets, note the boxes of ice in the foreground.

Plate 12. "Picking" fish from a commercial net on Southern Indian Lake.

Plate 13. Dressing whitefish while on the lake.

Plate 14. Carrying fish to the fish-house at Camp 3, Southern Indian Lake.

All winter fishing is presently done out of Loon Narrows between mid-January and mid-April. Fishermen usually limit the gear used to 7-10 gill nets (700 to 1,000 yds). The setting of gill nets under the ice is very time-consuming and nets are seldom moved once set. During the winter fishery the men would rather tole ate low catch per unit effort than move the nets.

Winter crews are usually composed of three or four men. Again, there may be three licensed fishermen, or two licensed fishermen with two helpers. To set a net, a hole about 2 ft x 2 ft is chopped in the ice and a line is attached to a "jigger". By pulling a rope attached to the "jigger" it moves under the ice. While in motion it makes a knocking sound and this is followed by a man walking over the ice. When 100 yds of line have been played out another hole is cut in the ice and the "jigger" retrieved. This is continued until enough line is out to string the number of nets desired. The "jigger" can only be used on very calm days because the wind blowing over the ice will drown out the knocking sound and make it impossible to retrieve. One hundred yard lengths of nets are then attached to the line under the ice and pulled into the water from the next hole. It is important to weight these nets well because if they float with a heavy catch they will freeze into the ice and are impossible to retrieve. The anchor lines are then tied to a stick which is frozen into the ice near the holes.

In lifting the nets the holes are chopped free of ice at both ends of the net. Then, the anchors at both ends are pulled, a line is attached to one end, and the net is retrieved through the hole at the other end. As the fish are picked the net is neatly placed on the snow (Plate 15). When the net is finished, it is reset by pulling on the line until the net is under the ice again. Then the anchors are reattached and the net dropped to the bottom. Each net is set and lifted separately. Once picked, the fish are dressed immediately (Plate 16). Extreme care is taken to prevent the fish from freezing because only fresh fish are purchased by the Co-op. If the fish are to be taken to Loon Narrows the same day, they are put into boxes and made ready for transport immediately after dressing. If not, they are buried in the snow to await pickup. Fish do not die as quickly in cold water, and nets are usually only tended every two to three days during the winter season.

To travel to and from the nets three methods are used. The first is by dog team. This is the slowest, being about half as fast as a bombardier or snow machine, but it is the most reliable. Most people who operate by dog team usually pay the Co-op 2¢/lb to pick up their fish at the nets. The second is by snow machine; this is the fastest method, but the amount of fish which can be delivered is limited. A good skidoo and sleigh on a good trail can carry over 1,000 lbs of fish. There are problems with the mechanical reliability of this method. The third method is bombardier. A bombardier can carry up to 3,000 lbs of fish, and it is very comfortable to

Plate 15. Pulling nets during the winter fishery on Southern Indian Lake.

Plate 16. Dressing fish during the winter fishery in Southern Indian Lake. Note the dog team in the background.

operate. However, it is very expensive to purchase and oper
vulnerable in slushy conditions and not overly reliable. Th
bombardier is an excellent means of moving fish if the machi
is mechanically sound. Once the fish are at Loon Narrows th
are sorted, weighed and packed on ice to await shipment to t
plant at Leaf Rapids (Plate 17 and 18).

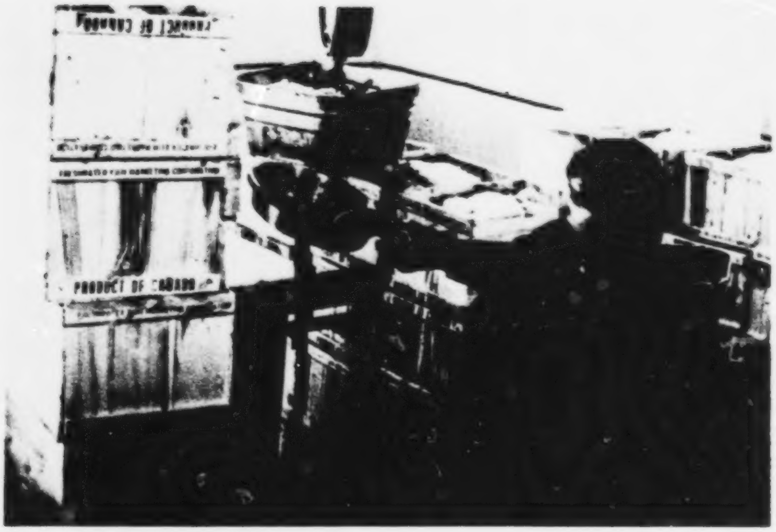

PRODUCT OF CANADA

Plate 17. Sorting and weighing fish in the fish-house at Loon Narrows, Southern Indian Lake.

Plate 18. The Southern Indian Lake Co-op Fisheries plant at Leaf Rapids, Manitoba.

5.3. WINTER FISHERY

5.3.1 Past Production:

The past production for the winter fishery on Southern Indian Lake is summarized in Figures 14 and 15. The production has varied considerably since the beginning of the fishery in the winter of 1941-42 with the highest production being 932,800 lbs in 1946-47 and the lowest being 20,600 lbs during the first year of production, 1941-42. The average production/season for the 30 years the winter fishery has (not including 1972-73), been 455,626 lbs.

Whitefish is the most important species in the winter fishery and accounts for an average of 95.4% of the commercial catch, yellow pickerel account for an average of 3.9% of the landings and pike account for the remaining 0.7% (Table 4). Whitefish have contributed as high as 100% and as low as 64.2% of the total landings over the past 30 years.

During the early years of the winter fishery (until the winter of 1947-48) lake trout were included in the quota. In 1943-44 the province of Manitoba recorded 100 lbs of trout taken from the lake; however, no local fishermen have ever remembered having caught trout and suggested these trout may have been caught in other lakes in the area and sold to buyers on Southern Indian Lake.

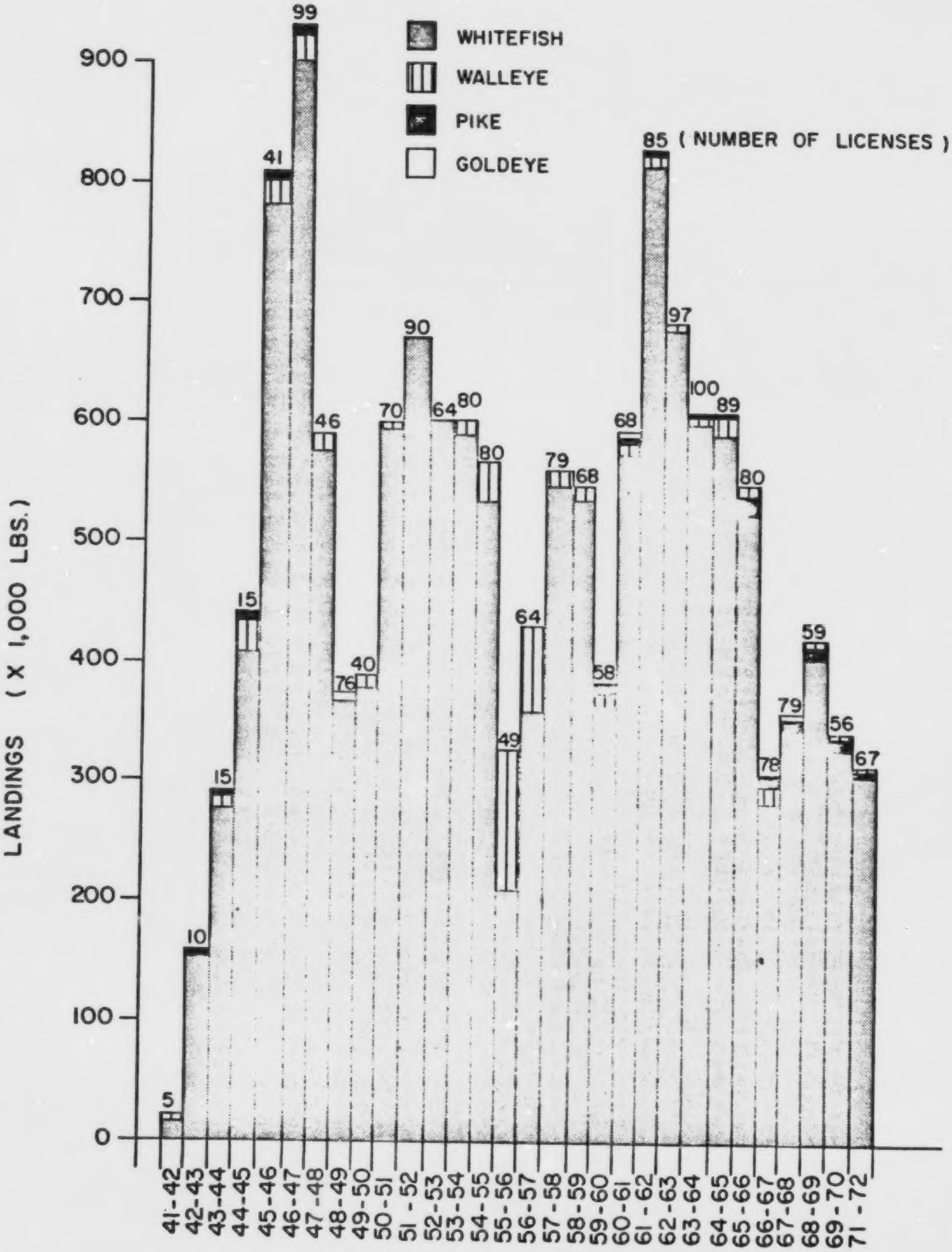


Figure 14. Total landings by species for the winter fishery from the 1941-42 season to the 1971-72 season.

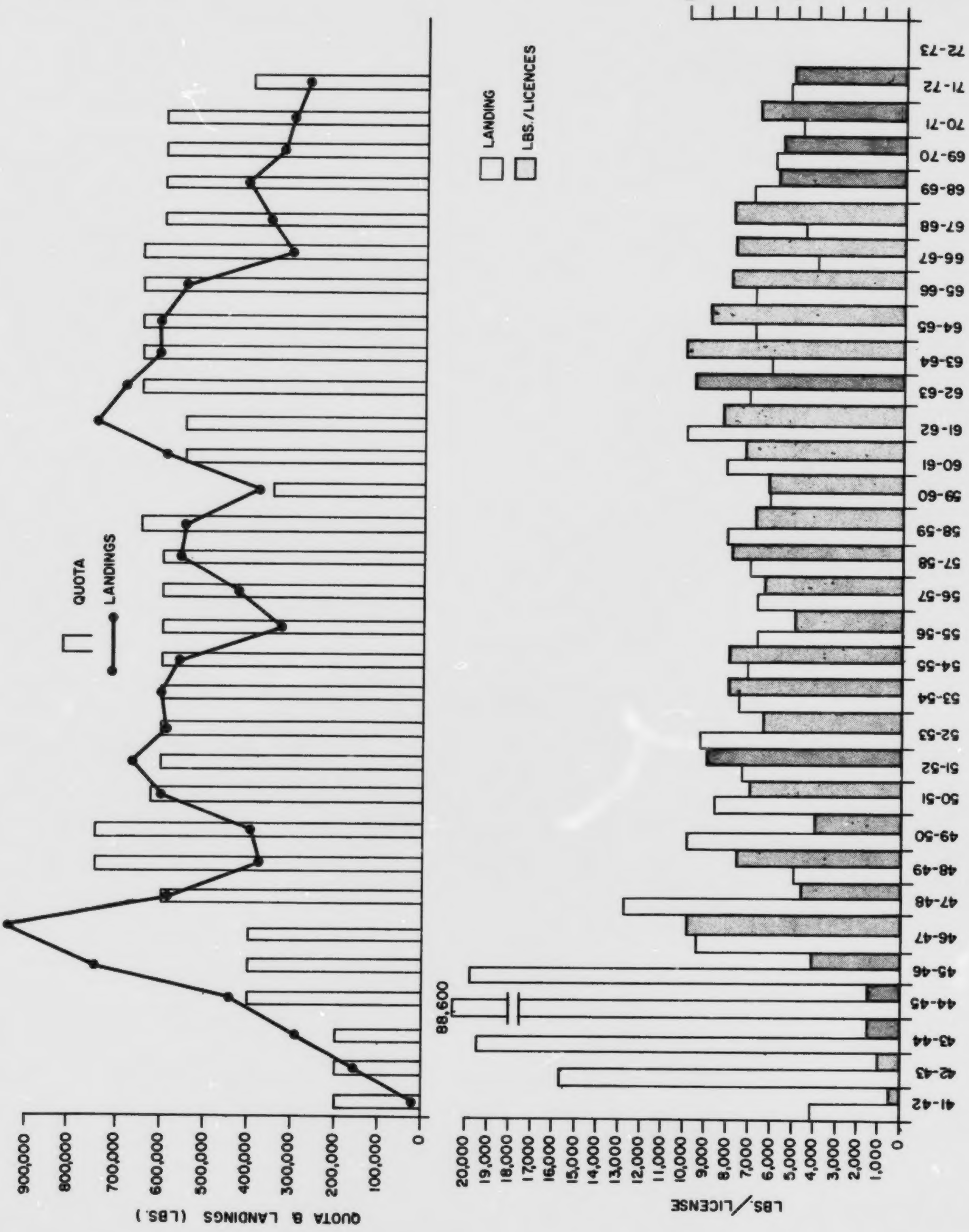


Figure 15. Number of licenses, average pounds taken per license, quota and landings for the winter seasons on Southern Indian Lake from 1941-42 to 1971-72.

Table 4. The average landings/winter season, average landings/license, average percent whitefish and average percent pickerel in landings for 5 year periods beginning in the 1941-42 season.

Season	Average landings per season (lb)	Average landings/ season/license (lb)	% whitefish	% walleye
1941-42 to 1945-46	199,120	29,566	95.9	3.1
1946-47 to 1950-51	507,920	9,147	97.2	2.6
1951-52 to 1955-56	544,680	7,640	89.5	10.5
1956-57 to 1960-61	503,140	7,237	94.6	5.1
1961-62 to 1965-66	657,540	7,403	98.3	0.9
1966-67 to 1970-71	347,320	5,253	97.0	1.4
1971-72	276,000	5,307	98.9	0.5
Ave. for all years	455,626	10,856	95.5	3.8

Production in the first five years of the fishery was low, at an average of 199,120 lbs/year. This was most likely related to lack of fishermen (averaging 17/year), rather than the lack of fish; during this period the fishermen averaged 29,566 lbs/year/license. The next twenty years (1946-47 to 1965-66) were fairly consistent at an average of 555,820 lbs/year. The average landings per license during this period dropped slightly from an average of 9,147 lbs/license/year in 1946-51 to an average 7,403 lbs/license/year in the 1961-66 winter seasons. The average number of licenses per year during these twenty years was 74.

The last 6 years have seen a drop in the winter production on Southern Indian Lake to an average of 335,434 lbs/year. The average production/license has also dropped slightly to 5,247 lbs/license/year and the average number of licenses per year has dropped to 65. It should also be noted that during the 1971-72 winter season, the quota was dropped from 600,000 lbs to 400,000 lbs (Figure 15 and Appendix V).

It is interesting to note that the decrease in the winter fishery does not indicate a poorer fishery. During the period of decrease in the winter production, there was an increase in summer production (Section 5.4.1.). A detailed analysis of the 1972-73 winter production can be found in Section 5.3.5.

Distribution of the landings amongst the licenses was available only for the 1970-71 and 1971-72 seasons (Figure 16). (This data was from the Economics Branch of Environment Canada, Fisheries and Marine Service and does not agree with the other data for the same period which was from the Manitoba Rept. of Mines, Resources and Environmental Management). In the 1970-71 season 67% of the fishermen had less average production/license (lb/license) and in the 1971-72 season 77% here had less than average (average was 6,753 lb/license) indicating that there were considerably more poor fishermen (less than average production) than good fishermen (more than average production) during these two seasons. This fact and the variations in production per license make the predicition of future production very difficult.

5.3.2 Past value to fishermen:

Table 5 and Figure 17 summarize the value to the fishermen of the landings over the 31 years for which we have data. The higher values during the 1961-62 to 1970-71 seasons cannot be accounted for with our present knowledge. During certain seasons, 1944-45 and 1961-62, the higher values could be directly related to higher landings, in other years it could indicate variation in the pricing system, on which we have little information.

Average value/license for the winter fishery which can be looked at as the fisherman's average gross income for the season, have increased from $507 during the period of 1946-1951 to $1,133 during the period of 1966-1971. This increase is due to inflation

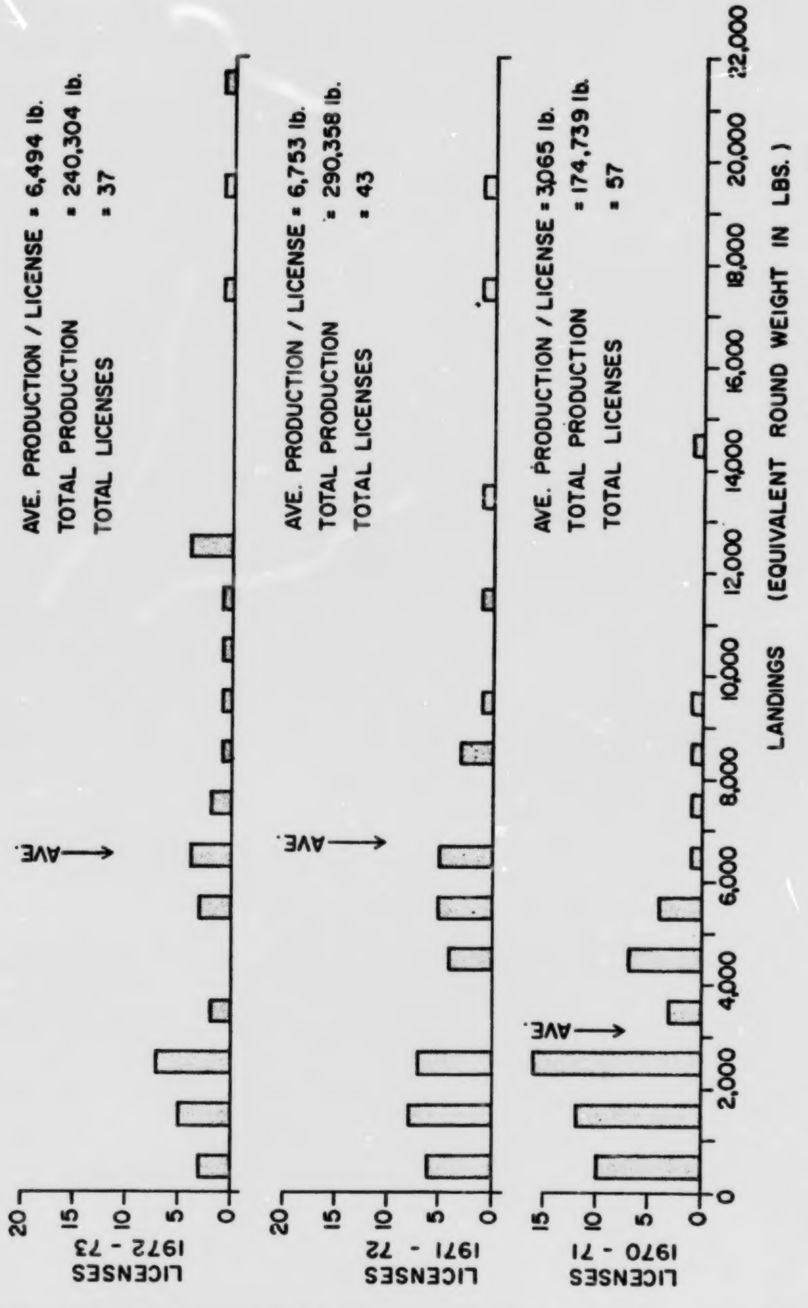


Figure 16. Production distribution among fishermen for the 1970-71, 1971-72 and 1972-73 winter seasons on Southern Indian Lake, the average production per license is indicated for each year by the arrow.

Table 5. Average value to the fishermen, average number of licenses and average value per license for the past 31 years of the winter commercial fishing on Southern Indian Lake. (Data source, Manitoba Dept. of Mines, Resources and Environmental Management)

Seasons	Average Value	Average Licenses	Average Value per License
1941-42 to 1945-46	$ 26,064	17	$ 1,339
1946-47 to 1950-51	32,820	66	507
1951-52 to 1955-56	39,143	73	559
1956-57 to 1960-61	47,756	69	697
1961-62 to 1965-66	116,034	90	1,298
1966-67 to 1970-71	75,592	68	1.133
1971-72	33,439	52	643
Average for period	55,499	63	913

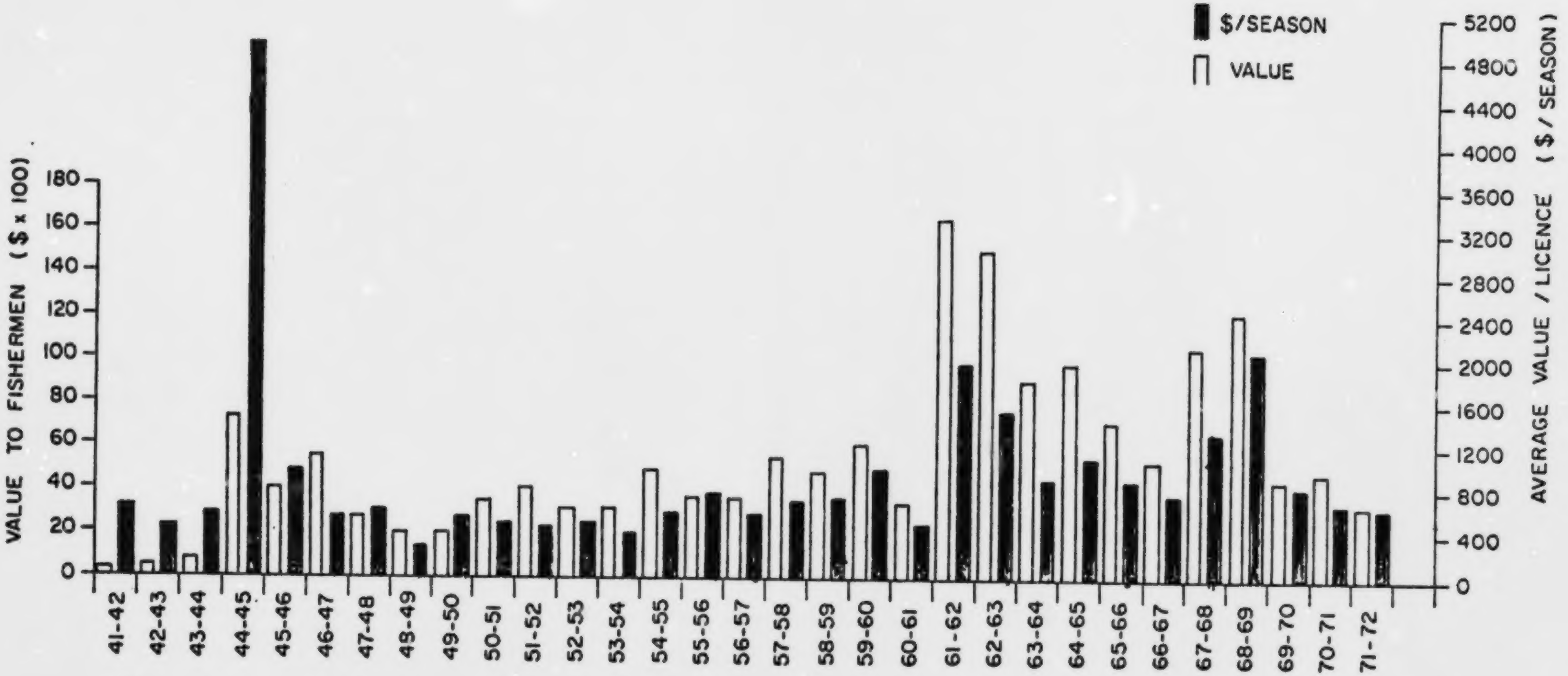


Figure 17. Total value to the fishermen and average value per license for the winter seasons on Southern Indian Lake from 1941-42 to 1971-72.

and not increased production (during the same period production dropped). The average value/license during the 1941-1946 period of $1,339 was due to the high landings (88,600 lb/license) in the 1944-45 season which resulted in an average value/license of $4,9

The income/license distribution for the 1970-71 and 1971- seasons are shown on Figure 18 (again it is cautioned that this data comes from Environment Canada and does not agree with the Province of Manitoba data). During both of these seasons 67% of the fishermen had earnings less than the average; and during 1970- 70% had incomes of less than $500.

5.3.3 Past Transportation:

During the first year of winter operations the fish were shipped from Southern Indian Lake by air. This proved to be expe sive but had the advantage of being able to ship the fish fresh and therefore demand a higher price. As stated earlier T. Lamb soon switched to "Cat-swing" and shipped only frozen fish.

Information on shipment methods is scarce but conversatio with the fishermen indicated the major buyers usually used a combination of Bombardier and plane to ship their fish. In the mid to late '60's the trend was to ship as much as possible by Bombardier, however, with frequency and cost of repairs being so high, Bombardier rates are now approaching air rates (1972-73 season air rates were from 1¢-2¢ higher).

Air shipment does have the advantage of being fast and

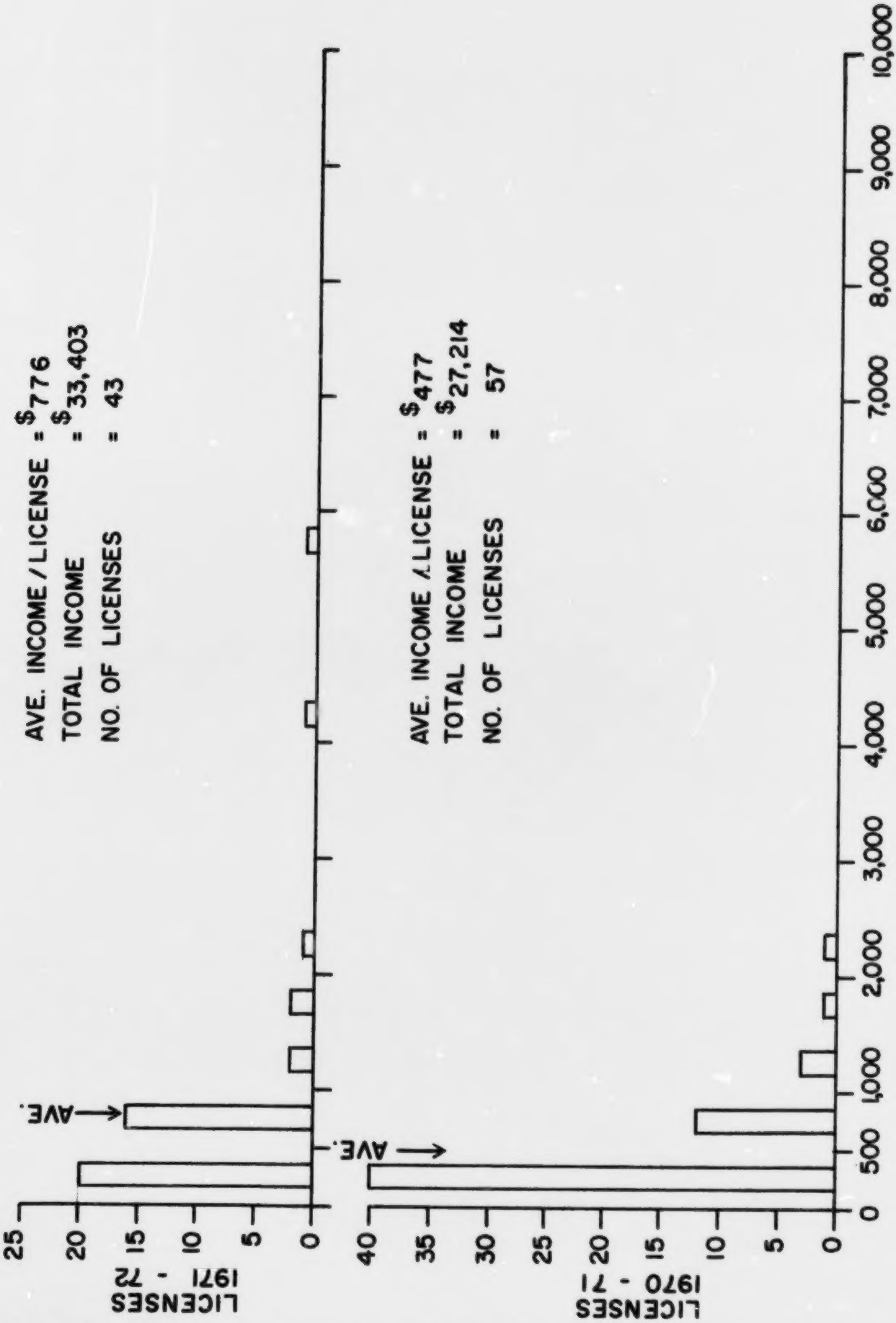


Figure 18. Income distribution among the fishermen for the 1970-71 and 1971-72 winter seasons on Southern Indian Lake.

results in a minimum of delay between the net and the plant. Recently there also seems to be no lack of aircraft in the nort and breakdowns are not common.

In the 1940's fish was shipped to Wabowden and Sherrido but in recent years all fish has been shipped to the rail-head Lynn Lake.

5.3.4 Trends based on past history:

To pursue the winter commercial fishery in the sub-arct regions of Canada takes a hardy type of being. It appears that Southern Indian Lake these men are becoming scarce. Although t number of licenses issued in recent years hasn't dropped alarmi the number of fishermen who fish all season has. It appears, however, that the men who do fish are still enjoying good produ tion and the total production is only falling slightly.

With the quota system that is presently in effect the amount produced is controlled artificially. It is safe to say Southern Indian Lake, in its natural state, can have a sustaine yield for the winter fishery of 400,000 lbs of whitefish and pickerel per season. If the less valuable species such as burb suckers, pike and cisco are fished the sustained yield will be even higher. Before any quota is raised, however, the entire system should be re-examined.

The fact that the production has not reached the quota recent years could be related to the price of fish in winter (or

Southern Indian Lake this is about 4¢/lb lower than summer because of increase shipping costs), lack of participation in the winter fishery, and problems in maintaining winter transportation equipment, rather than an actual reduction in the fish stocks. The stocks at present don't appear to be in danger of being over-fishe

Predicting the value of the fishery in the future is extremely difficult. If the production cannot exceed the quota of 400,000 lbs then the value of the fishery is dependent on the pricing system, the transportation costs, and marketing and produc trends. If a market can develop for the less desirable species listed above the value could increase substantially, if not the value will only increase as the demand for fish increases.

5.3.5 Analysis of the winter production 1972-73:

The 1972-73 winter fishing season got off to a slow start (season January 14 to April 10), by the end of the first week ther were only 5 operators (17 men) fishing out of Loon Narrows. Altho the catches were high, it seemed some men preferred to work at othe jobs and only 37 licenses were fished during the season. By early March the catch per unit of effort (C.U.E.) had fallen, and fisher men were beginning to pull nets and leave. By April few fishermen were left at Loon Narrows, and only 20 deliveries were recorded during the week of April 1st to the 8th.

The lack of detailed information on previous years makes it difficult to say whether or not this was a typical season. The

average catch/license of 6,438 lb was higher than the 197
season (5,307 lb/license) and also higher than that for t
1971 period (average - 5,253 lb/license). The landings (
lb), however, were down from 1971-72 and well below the 1
average season landings of 347,320 lbs.

5.3.5.1 Catch per unit of effort:

Data on catch per unit of effort (c.u.e.) was col
for weeks 1 to 4 and 7 to 11 of the winter commercial sea
During the first week the average c.u.e. for the fishery
lb/net/day (these weights are dressed weight for whitefis
headless, dressed for walleye and pike). The highest c.u
recorded, 217 lb/net/day, was during this period.

As the season progressed the c.u.e. dropped until
and then leveled off at around 18 lbs/net/day (Figure 19)
reason for the decline in c.u.e. is discussed in Section

5.3.5.2 Age composition of commercial catch and mortality

The average age of the whitefish taken by the win
mercial fishery in 1973 was 8.7 years, the youngest fish
was VI+ years and the oldest was XIII+ years. Table 6 gi
breakdown by week of the age data. The strongest year cl
IX followed by VIII and X. For the 4 weeks during which
were taken there were no significant differences (Student
95% confidence limits) between the average ages.

The whitefish mortality rate (calculated using Ri

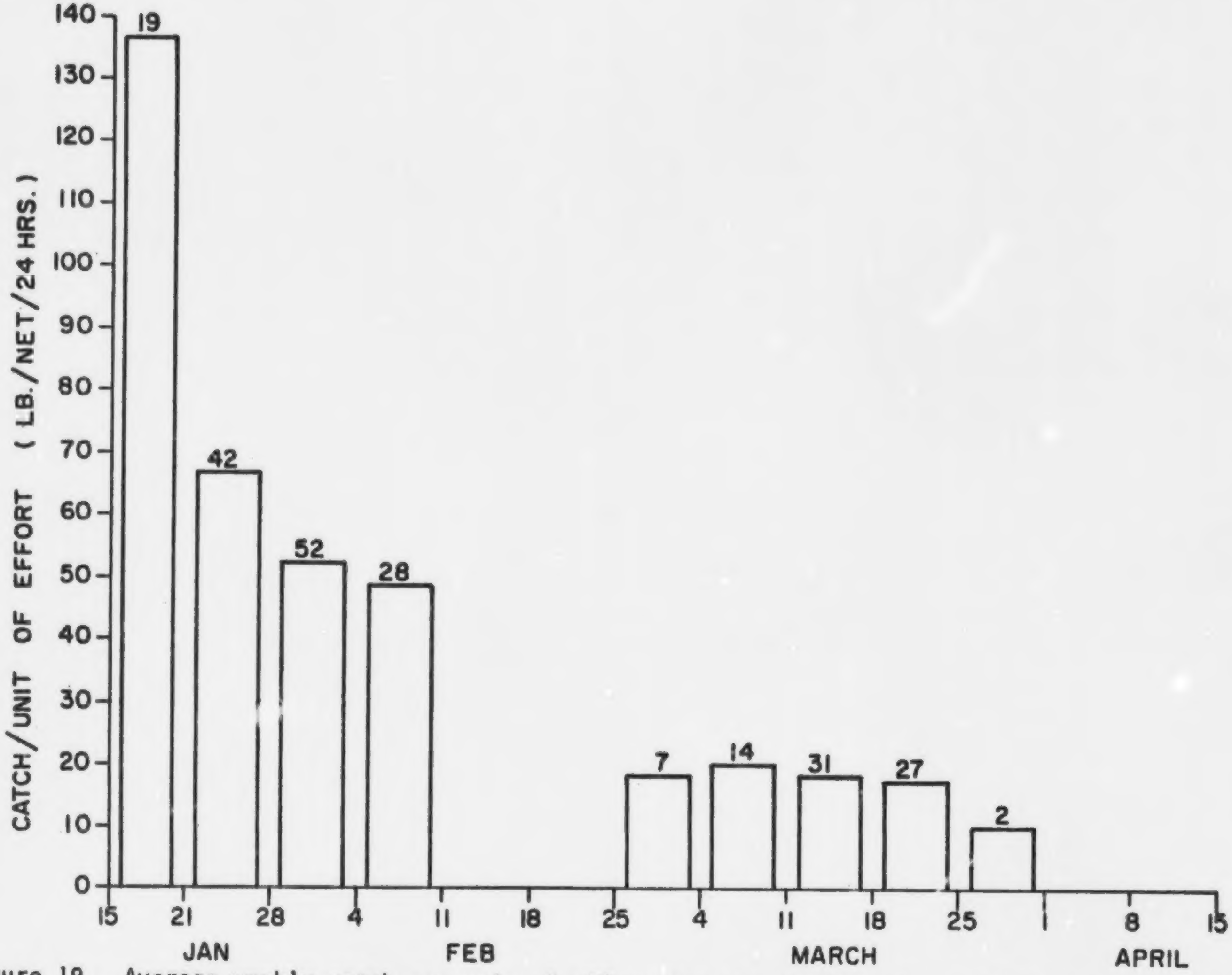


Figure 19. Average weekly catch per unit of effort for the 1972-73 winter fishery on Southern Indian Lake (the numbers represent the number of fishermen sampled).

Table 6. Age distribution for a random sample of fish caught in the commercial fishery Southern Indian Lake during the winter fishery of 1972-73. The Ike Island and Loon Narrows samples are from fish caught in nets near those two locations.

Location or Week	Age (years$^+$)										
	6	7	8	9	10	11	12	13	$\bar{x}$	SD	N
Jan 15-21	6	7	21	22	10	3	-	-	8.5	1.24	68
Jan 22-28	2	10	29	28	14	9	-	-	8.8	1.20	92
Jan 29-Feb 4	-	17	19	28	13	3	1	-	8.6	1.17	81
Feb 5-11	-	7	8	14	13	1	-	1	8.9	1.26	44
Total for above	8	40	77	92	50	16	1	1	8.7	1.21	285
Ike Island	4	18	15	7	5	-	-	-	8.8	1.11	49
Loon Narrows	1	7	6	6	2	1	-	-	8.2	1.23	23

was 73% for fish from X to XIII years. This compares favorably with mortality rate for whitefish from other exploited populations, and is not much higher than the mortalities for unexploited whitefish populations (Table 7). It should be remembered that this not only reflects the mortality due to fishing but also the natural mortality. It has also been suggested that data collected in this manner, from the commercial gill netting, tend to overestimate mortalities because of net selectivity (Cucin and Regier 1966). The mortality rate and the presence of several consecutive, strong year-classes indicates the whitefish population on the winter fishing grounds is not being and has not been over-fished.

5.3.5.3 Catch distribution:

From our data the 1972-73 winter fishery on Southern Indian Lake produced 240,304 lb of fish; 37 licenses were fished during the season giving an average landing of 6,494 lb/license (Figure 16). There were 719 individual deliveries to the Co-op facilities giving an average of 19.4 deliveries/license and 334 lb/delivery. Figure 16 shows the distribution of the landings/fishermen being divided into 3 distinct groups; those producing less than 5,000 lb; those producing between 5,000 and 13,000 lb, and those producing over 13,000 lbs. This is also reflected in the average landings/delivery for the three groups; the first (producing less than 5,000 lbs) averaged less than 188 lb/delivery, the second group (5,000 to 13,000 lb/year) averaged 314 lb/delivery and the third group

Table 7. Estimates of lake whitefish mortality in both exploited and unexploited situations.

Author	Lake	Conditions	Mortality %	Year Classes	Year data collected
Kennedy (1963)	Nueltin,N.W.T.	Unexploited	57	13-16	
	MacDonald,NWT	"	81	11-14	
	MacEwen,NWT	"	74	8-10	
Kennedy (1953)	Great Slave,NWT	"	61	17-22	1944-1949
Ricker (1949)	Shakespear,Ont.	"	8	12	
	Shakespear,Ont.	"	45	27	
Edsall (1960)	Superior, Mich.	"	35	8-16	
Kennedy (1954)	Winnipeg, Man.	Exploited	64	6-11	1937-1951
Kewson (1959)	Winnipeg, Man.	"	86	7-15	1948-1953
Ricker (1949)	Nipigon, Ont.	"	55	13-20	1923-1924
Cucin & Regier (1966)	Huron, Ont.	"	77	5-6	1955
	Huron, Ont.	"	80	6-7	1954
Bond (pers. comm.)	Great Slave,NWT	"	58	12-17	1972

(greater than 13,000 lb/year) averaged 524 lb/delivery. Looking at the average number of deliveries for each weight range we find fishermen producing less than 5,000 lb/season averaged 10.4 deliveries/season (range: 3.3-17 deliveries/season); fishermen producing from 5,000 to 13,000 lb/season averaged 25.1 deliveries/season (range 20-33 deliveries), and fishermen producing over 13,000 lbs/season averaged 37.7 deliveries/season (range 28-43 deliveries/season).

The above clearly shows the three types of fishermen on the lake; first the occasional or poor fisherman, these are men who only fish sporadically, who generally have very low c.u.e. (average 33 lb/net/night) and who produce less than 5,000 lb/year. These fishermen held 46% of the 1972-73 winter season licenses. Second, the average fishermen, these men fish steadily throughout the season, have average or slightly above average c.u.e.(average 48 lb/net/night) and produce from 5,000 to 13,000 lbs/season, they also made up 46% of the fishermen. Third, the excellent fishermen these men fished very hard pulling their nets on the average every 2.2 days. They had the highest c.u.e. (ave. 76 lb/net/day), totalled over 13,000 lb for the season and made up 8% of the fishermen.

It can be noted (Figure 16) that during the present year 1972-73 there were far fewer 'poor' fishermen than in 1970-71 when they made up 82% of the fishermen and 1971-72 when they made up

58% of the fishermen. This may be due to several factors the prime one being alternate employment opportunities. During the present season there are many more jobs in and near the settlement than in past years, and it is felt that 'poor' fishermen are taking these jobs while the 'average' and 'excellent' fisherman are continuing to fish. This opinion was also expressed by the fishermen themselves.

5.3.5.4 Weekly variation in winter fishery:

The weekly landings peaked during the third week of the season (January 28 to February 4) at 30,894 lbs (Figure 20). From the seventh to the tenth week there was a steady decline, then a slight rise in the eleventh week followed by a steady fall to 6,221 lb during the twelfth week and no landings during the 13th and final week of the 1972-73 winter season.

At first this reduction in catch would appear to indicate a decline in the stock, a closer look seems to point to a different cause. The increase in weekly landings, weeks 1 to 3, was clearly related to increased effort, during the first week there were only 17 fishermen making an average of 2.9 deliveries for the week; by the third week there were 30 fishermen making an average of 2.8 deliveries for the week. Although the number of fishermen varied considerably between the first and seventh week the average deliveries per fisherman per week remained nearly the same (2.7 deliveries/fisherman/week). During the last 5 weeks of fishing the

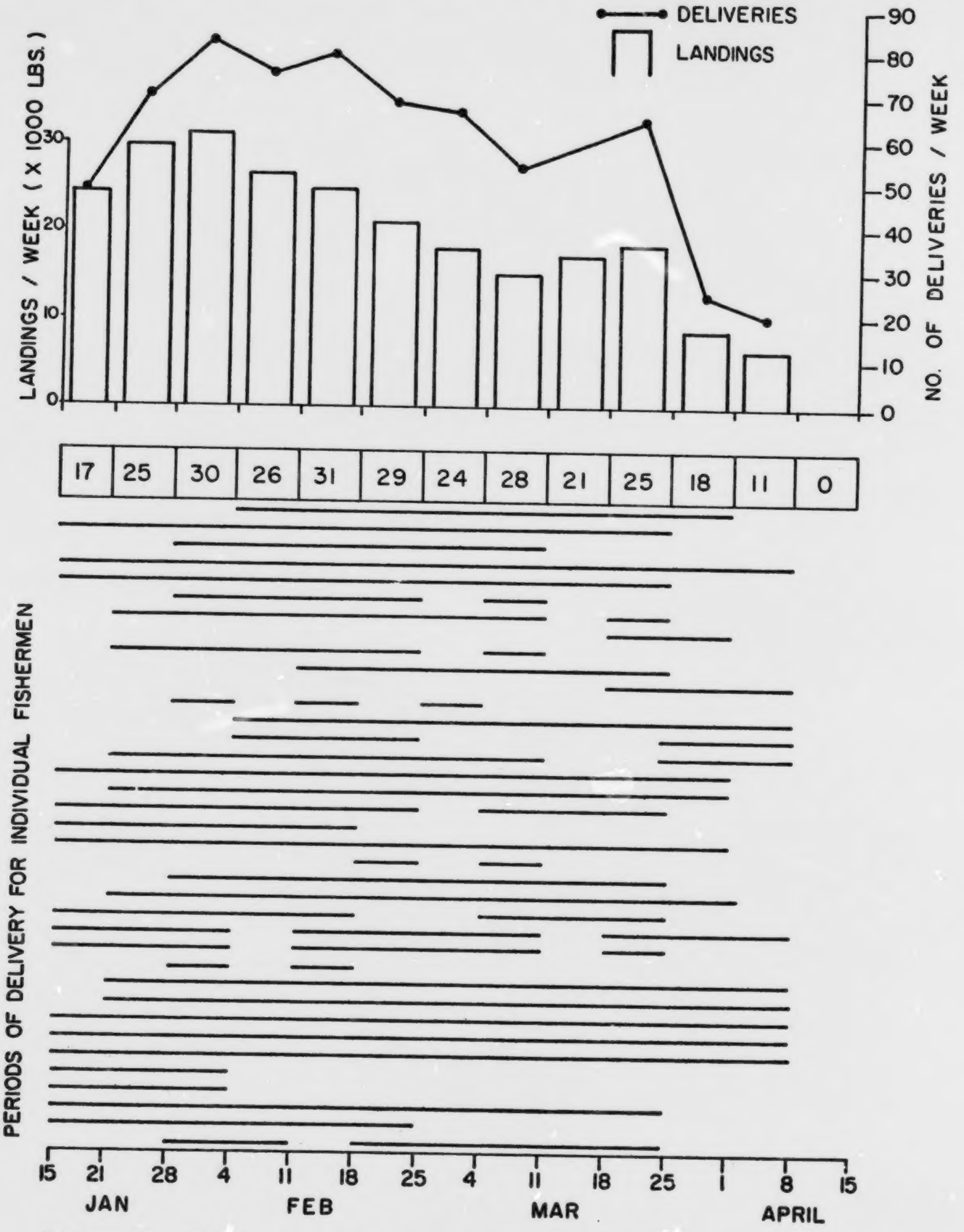


Figure 20. The landings per week, deliveries per week and the periods of activity for individual fishermen for the 1972-73 winter fishery on Southern Indian Lake.

deliveries/fisherman/week dropped as low as 1.4 and averaged 1.9. As the season progresses the number of fishermen as well as the number of deliveries per fisherman decreases, and the reduction in total landings can therefore be partially explained by a reduction in effort.

In Section 5.3.5.2 the steady decline in c.u.e. was mentioned. Fishing pressure could no doubt be responsible for some decline but one would think that if the larger fish were being removed there would be a reduction in the average age of the fish landed. Table 6 shows that the average age during first five weeks of the fishery did not change significantly. It is thought therefore that the reduced c.u.e. and the resulting reduction in weekly landings was caused mainly by fish movement. This view is also held by the fishermen themselves who claim the fish begin to move from one feeding ground to another in late winter and to maintain the large catches of the early winter the nets must be moved very often. Because of the difficulty involved in setting nets through the ice and the resulting equipment wear, the fishermen tend to move their nets very seldom during the winter fishery and will tolerate lower c.u.e. before moving than they would during the summer.

To summarize, the late winter decline in landings were the result of decreased fishing effort and lower c.u.e. caused by fish movement.

5.3.5.5 Distribution of Effort:

Fishing effort during the winter season is concentrated in three main areas (Figure 21). The first is north of Loon Narrows near Duck Narrows (Figure 21, Grids $8\text{-}C^1$, $9\text{-}B^1$, $9\text{-}D^1$), the second near Jam Island (Figure 21, Grid $15\text{-}G^1$) east of Loon Narrows and third just south of Long Point (Figure 21, Grid $20\text{-}A^1$). There were also areas of less intensive effort close to Loon Narrows.

5.3.6 Revenue Expenditure Analysis (Winter):

Appendix VII contains a revenue-expenditure analysis for selected fishing operations.

For the 1973 winter fishery 73% of the fishermen who sold fish to the Freshwater Fish Marketing Corporation received less than $1,500 gross revenue. This compared with 88% who received less than $1,500 in the previous winter, and 96% who received less than $1,500 in the 1971 fishery. This distribution of gross income suggests a low level of capital and labor are employed in the winter fishery. The short duration of participation made it very difficult to interview fishermen. Consequently, the winter survey was restricted to those fishermen who actively participated in the fishery. Of the 37 individuals who made fish sales to the Freshwater Fish Marketing Corporation, 11 were included in the survey.

Dog teams were used by 4 of the 11 fishermen who participated in the survey. These 4 fishermen grouped into 2 enterprises with the fishermen in each enterprise entering revenue-cost sha arrangements. Detailed revenue-expenditure accounts for these enterprises are provided in the appendix. Three useful calcula are the unit cost of production, the daily wage rate from fishi (the net return to labor for the "owner-operators" divided by t estimated man days participation in the fishery), and the breakeven point (the level of production at which total revenue equa total cost). For the dog team enterprises the daily wage rate f "owner-operators" ranged from $16-$32 per man per day. The cal lated breakeven points show that before a net return to labor fo the "owner-operators" accrued, it was necessary to produce from 2134 lb to 2620 lb of fish. The unit cost of production ranged from 5.89 ¢/lb to 6.73 ¢/lb.

The remaining 7 of the 11 fishermen who participated in the survey grouped into 4 Bombardier enterprises. Detailed reve expenditure accounts for Bombardier enterprises, are provided i the appendix. The daily wage rate ranged from $21.50-$47.00 pe man per day. Breakeven points ranged from 5560 lb to 9540 lb., although for 3 of the enterprises the breakeven point was in the 5500-6000 lb range. Unit costs of production ranged from 6.62 ¢ lb. - 11.01 ¢/lb.

5.3.7 Present state of winter fishery:

As documented above, winter production has been decreasi for several years. The decreased production can be related to decreased effort (fewer fishermen) with average production per fisherman remaining fairly constant. It appears the winter fishery could produce the 400,000 lb quota if the appropriate effort were exerted. The fishermen appear to be less enthused about the winter fishery because of the low financial returns and problems with equipment. This lack of enthusiasm most likely will increase as alternate employment opportunities increase and winter production will decrease even more. The fish, however, are available.

At present the problems associated with the fishery are mainly caused by the winter transportation system. The lack of dependable transportation makes it impossible for the fishermen to use more efficient techniques and is very demoralizing. The snow machines presently available do not stand up to the work required of them and most of the Bombardiers purchased require considerable maintenance to remain operational. The purchase of new machines is usually out of the question because of the cost (approximately $14,000).

In summary the winter fishery from a biological standpoint remains in an excellent position; however, adverse social and economic factors have led to decreased production.

5.4 SUMMER FISHERY

5.4.1 Past production:

The past production for the summer fishery on Southern Indian Lake is summarized in Figures 22 and 23 and Table 8. T summer landings have increased steadily since the first season 1950 when only 195,800 lb were produced until in the 1972 seas 712,900 lb were produced. The general success of the summer s is indicated by the landings reaching or exceeding the quota i of the 23 years the fishery was pursued. The quota itself has seen repeated increases with it presently standing at 800,000

The average landings/season for the 23 years was 429, lb and the average landings/license/season was 7,473 lb. Whit fish on the average composed 86% of the landings of walleye, and the remaining 1% was made up of pike and goldeye. Whitefi ranged from 94% to 72% of the total catch, walleye ranged from 26% to 6%.

Goldeye were fished in South Bay. This area has not b fished in recent years (last season was 1969). The last golde landings were in 1967 when 100 lbs were taken. During the 197 experimental fishing program (Ayles, MS 1973) there was one go eye netted at station 62, the abundance of the species in the is not known but at present it is believed to be extremely sca

The distribution of the landings amongst the fishermen

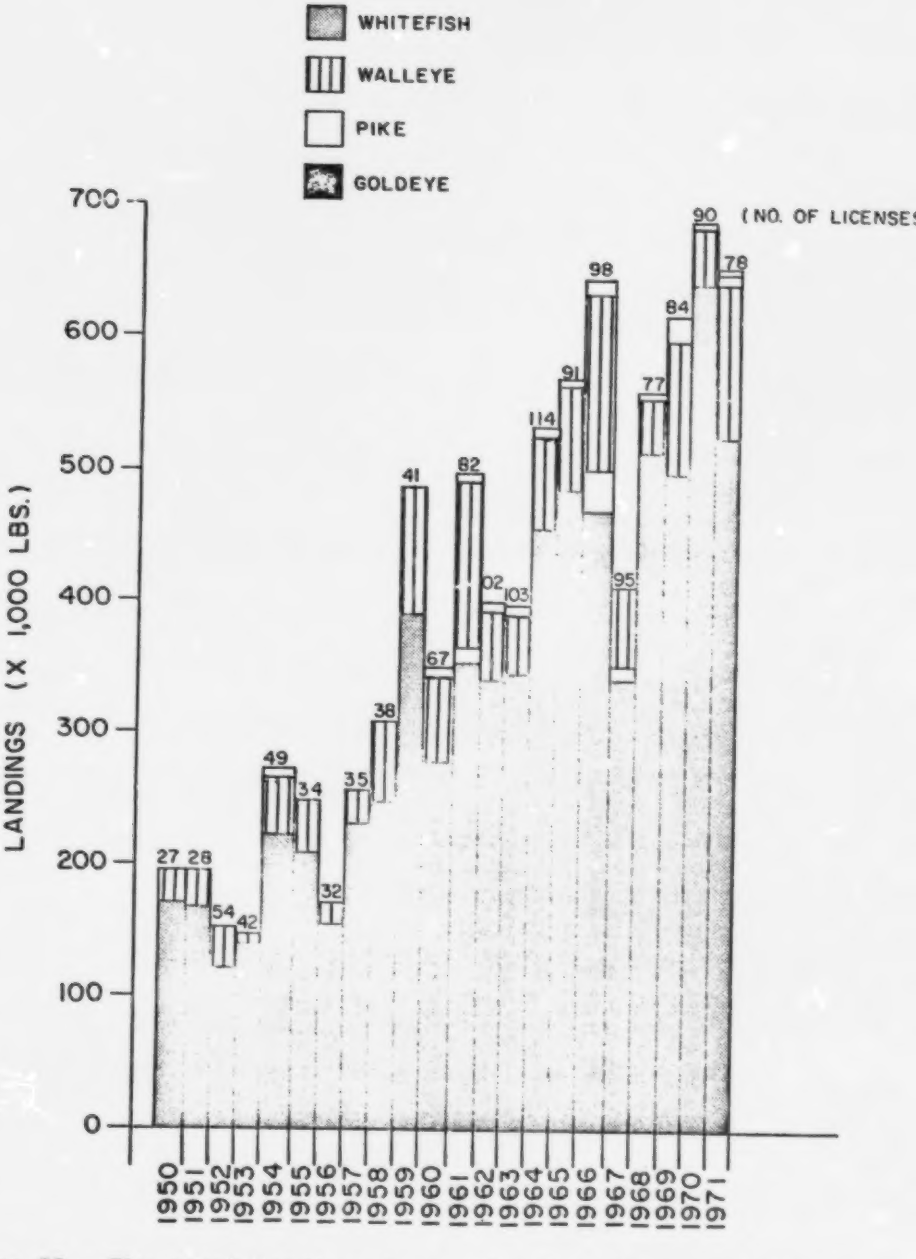


Figure 22. The total landings by species for the summer seasons on Southern Indian Lake from 1950 to 1971.

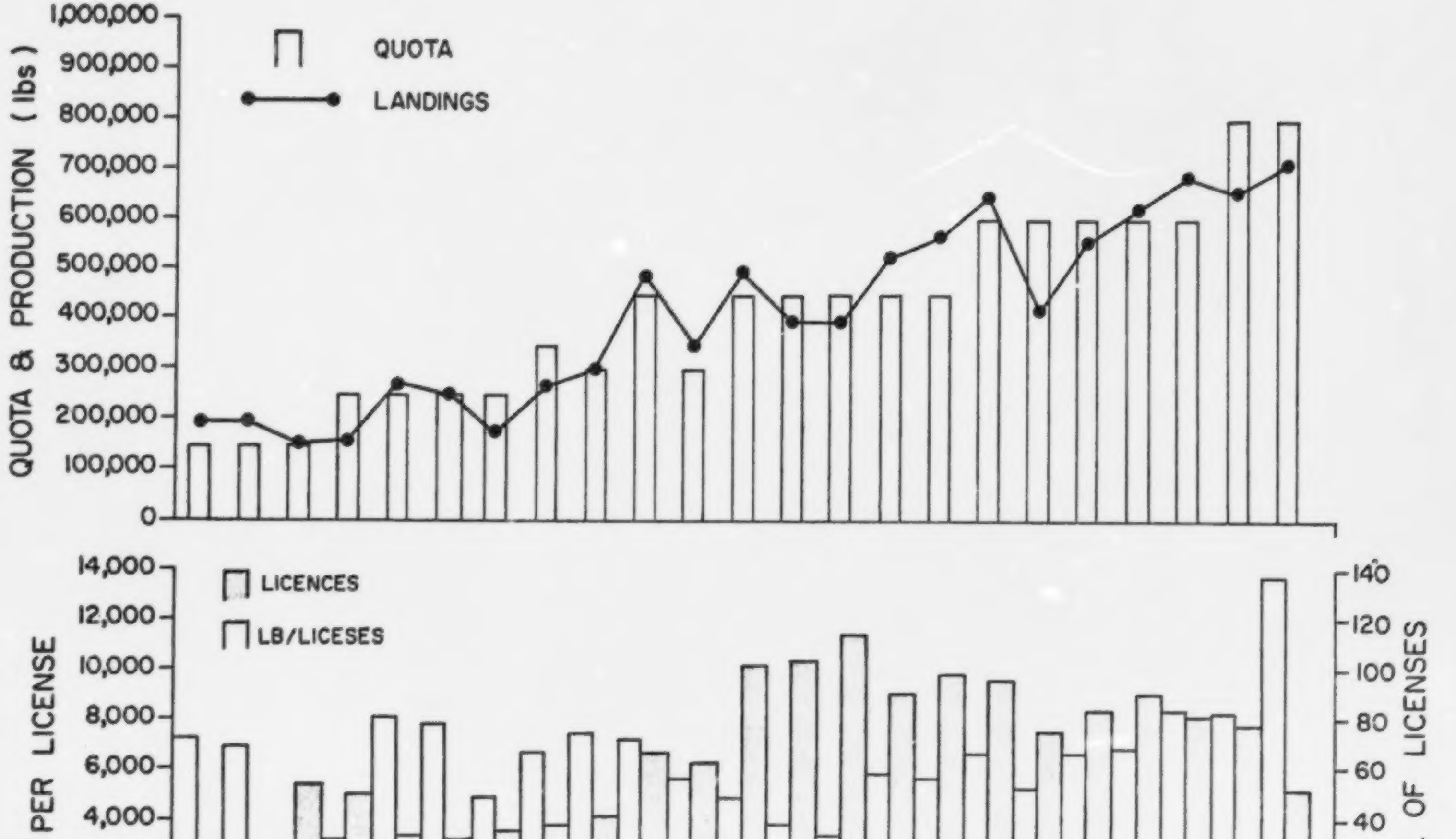

QUOTA & PRODUCTION (lbs)
1,000,000
900,000
800,000
700,000
600,000
500,000
400,000
300,000
200,000
100,000
0
QUOTA
LANDINGS
PER LICENSE
14,000
12,000
10,000
8,000
6,000
4,000
LICENCES
LB/LICESES
OF LICENSES
140
120
100
80
60
40

Table 8. The average landings per summer, average landings/season/licenses, % whitefish, and % walleye in catch for the summer seasons on Southern Indian Lake grouped in 5 year periods.

Seasons	Average landings/ seasons	Average landings/ license/season	% whitefish	% walleye
1950-51	195,150	7,098	87	13
1952-56	200,740	5,351	86	14
1957-61	379,340	6,408	80	19
1962-66	506,380	5.138	82	15
1967-71	585,420	7,139	89	10
1972	712,900	13,709	91	6
Ave. for all seasons	429,988	7,473	86	13

shown on Figure 24. In 1970, 61% of the fishermen produced less than the average.

5.4.2 Past value to fishermen:

The average values/season and average income/license/season are shown in Table 9 and Figure 25. As stated when discussing the value of the winter production (Section 5.3.2), the values of the catch may be misleading because of increases caused by inflated prices. The steady increase in the average value/season is dependent on two things, the increased production over the years and the increased fish prices, both production and fish prices have increased substantially between 1950 and 1972 leading to the value increase from $9,790 in 1950 to $149,807 in 1972.

5.4.3 Past transportation system:

As with the winter fishery, transportation also looms as a problem with the summer fishery. The only method of transporting fish from Southern Indian Lake during the summer until 1972 was by air. In 1971 the road link between Lynn Lake and the developing townsite of Leaf Rapids was opened, this provided the much needed road link between Southern Indian Lake and the rail-head at Lynn Lake. In 1972 the Southern Indian Lake Co-op Fisheries Ltd. purchased two 50' diesel-powered freighting vessels, during their first summer of operation they carried over 700,000 lb of fish from the lake to the new processing plant at Leaf Rapids and were also used to back-haul supplies needed at the fish camps. The

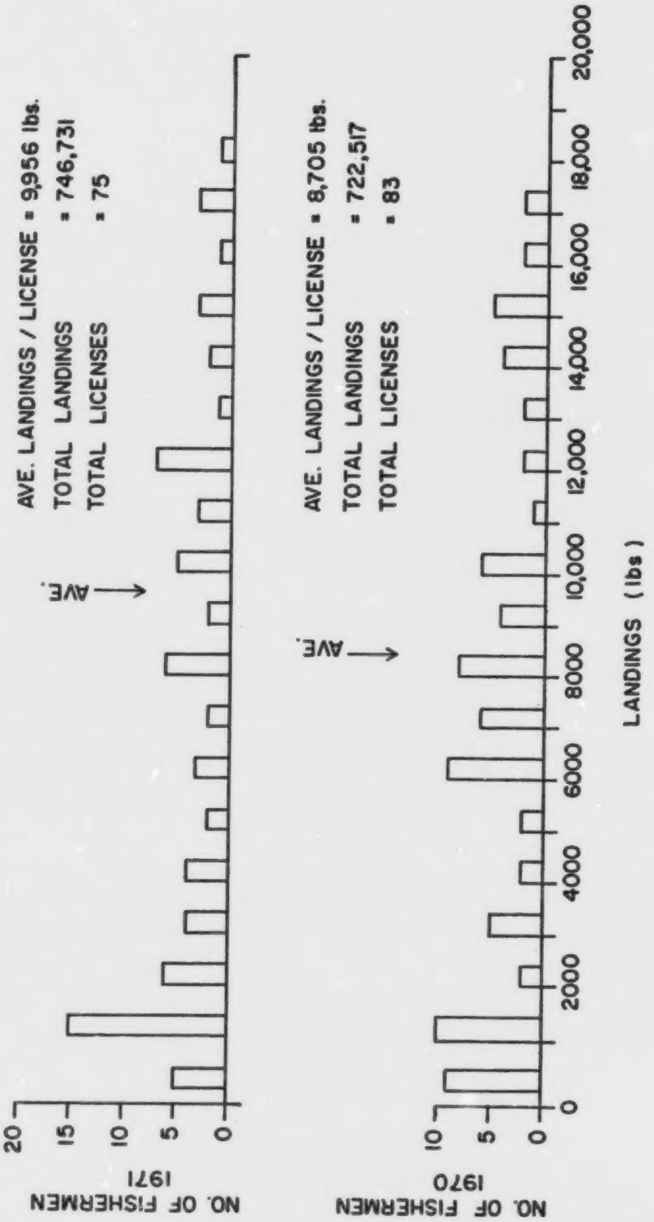


Figure 24. The distribution of landings among the fishermen for the 1970 and 1971 summer seasons on Southern Indian Lake.

Table 9. Average value per season, average income per season per fishermen and the average number of licenses per season for the summer fishery from 1950 to present, averaged over 5 year periods.

Seasons	Average value/ Season	Average Income	Average Licenses
1950-51	$ 8,926	$ 325	28
1952-56	11,706	323	41
1957-61	27,363	499	62
1962-66	59,496	599	100
1967-71	81,193	986	82
1972	149,807	2,880	52
Ave. for all seasons	$ 56,415	$ 935	61

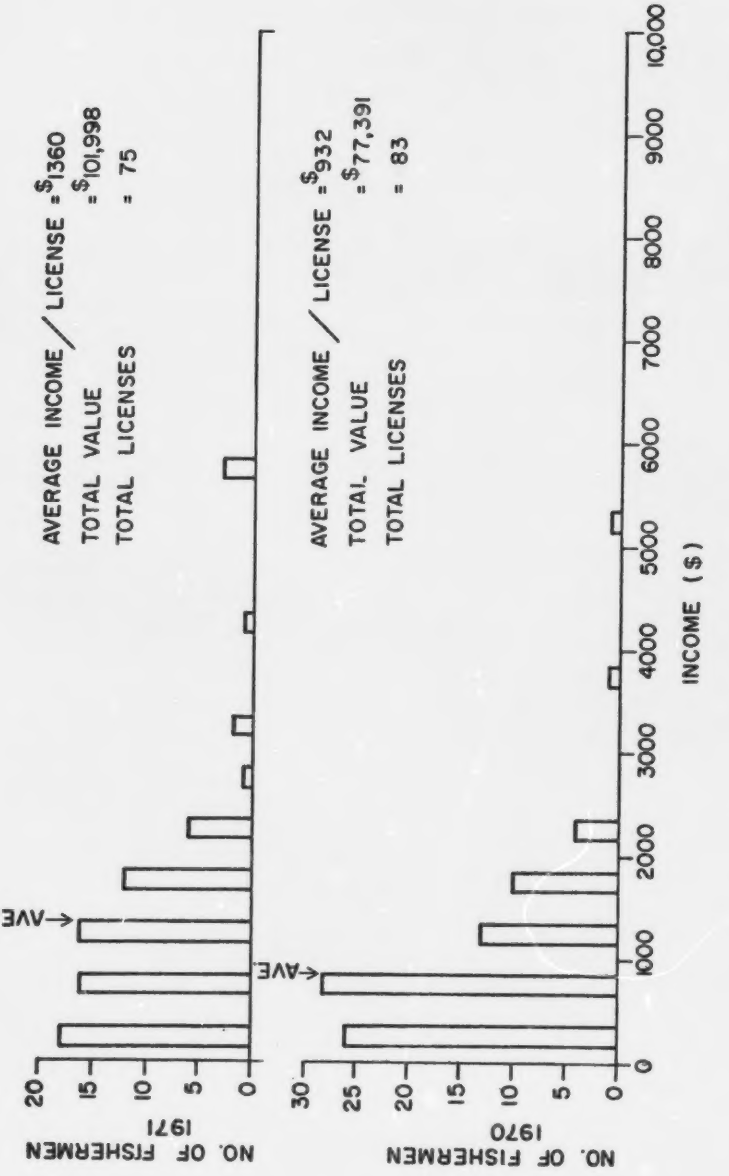


Figure 25. Distribution of the income among the fishermen for the 1970 and 1971 summer seasons on Southern Indian Lake.

fish were then taken by truck to Lynn Lake. This new system of water and ground transportation cut transportation costs and should lead to a more profitable summer fishery.

5.4.4 Trends based on past history:

From the first season (1950) the summer fishery on Southern Indian Lake has been a successful venture. The fish are plentiful and easily caught and over the past 23 years the production has steadily risen as the fishermen gained the needed experience in pursuing the summer fishery. The increased production in recent years, since 1966, appears to be due to a better knowledge of the fishing grounds and fishing methods because the fishing effort (number of fishermen per season) has dropped considerably (from the 1962-66 seasonal average of 100 fishermen, to 52 fishermen for the 1972 season).

The trend appears to be toward increased summer production and decreased winter production. The increased summer production, however, is still below the quota. The experimental fishing data (Ayles, MS 1973) suggests the whitefish population is in no danger of being over-fished at the present rate of exploitation. It appears safe to assume that the lake can support a sustained yield of 800,000 lb for the summer fishery.

The reduction in effort in recent years is likely to continue; this could result in reduced production. The revenue-expenditure analysis (Section 5.4.6) shows that a profit can be made by fishing on Southern Indian Lake if a high fishing effort is maintained by the individual fishermen. Based on past information there is no reason to believe the fishery is declining or will decline with the lake in its natural condition.

5.4.5 Analysis of the Summer Production, 1973:

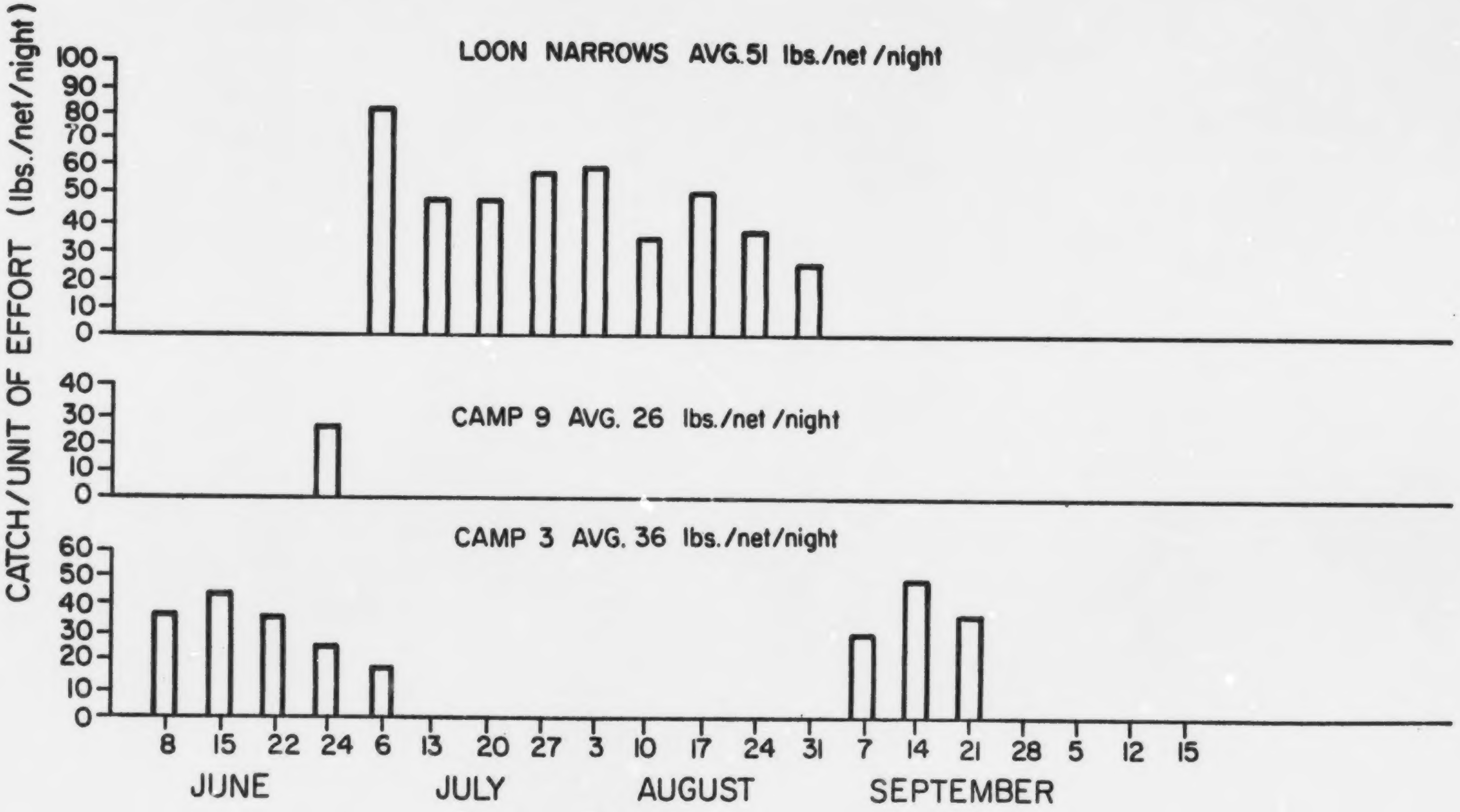
Fishing began on June 1, 1973 and continued until October 15th. The production was slightly higher than the previous summer season, 725,085 lb and there were 63 licenses fished. The fishing pattern for the season followed the traditional trend, during June and early July the activity was centered near Camp 3, in early July most of the fishermen moved to Loon Narrows with a few staying a week or so at Camp 9. In September, with the onset of bad weather activity moved back to Camp 3.

The average production per license, 11,509 lbs/license, was slightly lower than 1972, but overall the season was considered a good one by the fishermen.

5.4.5.1 Catch per unit of effort:

Data on c.u.e. were collected from the first week of June until the third week of September at Camp 3, Camp 9 and Loon Narrows (Figure 26). The average c.u.e. was 51 lbs/net/24 hours for Loon Narrows, 36 lbs/net/night for Camp 3 and 26 lbs/net/24 hours for Camp 9.

The average weekly c.u.e. at Camp 3 tended to drop in late June and early July. This may have triggered the move to Loon


CATCH/UNIT OF EFFORT (lbs./net/night)
LOON NARROWS AVG. 51 lbs./net/night
CAMP 9 AVG. 26 lbs./net/night
CAMP 3 AVG. 36 lbs./net/night
100
90
80
70
60
50
40
30
20
10
0
8
15
22
24
6
13
20
27
3
10
17
24
31
7
14
21
28
5
12
15
JUNE
JULY
AUGUST
SEPTEMBER

Narrows. Similarly the average weekly c.u.e. at Loon Narrows tended to drop in late August. This drop was not felt to represent the true situation. Our c.u.e. was calculated from the weight of fish delivered to the fish house, during this period bad weather usually prevents the fishermen from attending their nets daily and therefore increase the culls due to spoiled fish. These culls were not added to the actual fish bought, and resulted in an apparently lower c.u.e. From experience at Loon Narrows in 1972 the c.u.e. usually increases in the early fall due to pre-spawning whitefish migrations.

5.4.5.2 Age composition of commercial catch and mortality:

Figures 27 and 28 show the age composition of random samples of fish from Camp 3 and Loon Narrows respectively for various periods of the fishery. The samples for June 19 and 21 from Camp 3 indicate the commercial fishery is cropping in the VII, VIII and IX ages with the X and XI ages becoming more important in the June 26 samples. The influx of X and XI year fish may have indicated the return to the area of the spawning fish which are believed to migrate north to the Loon Narrows area in late August.

5.4.5.3 Catch distribution:

The distribution of the catch amongst the fishermen during the 1973 season differed greatly from preceeding seasons (Figure 29 for present season and Figure 24 for previous seasons). During 1973 there were 21 fishermen (33%) with total catches over 13,000 lb

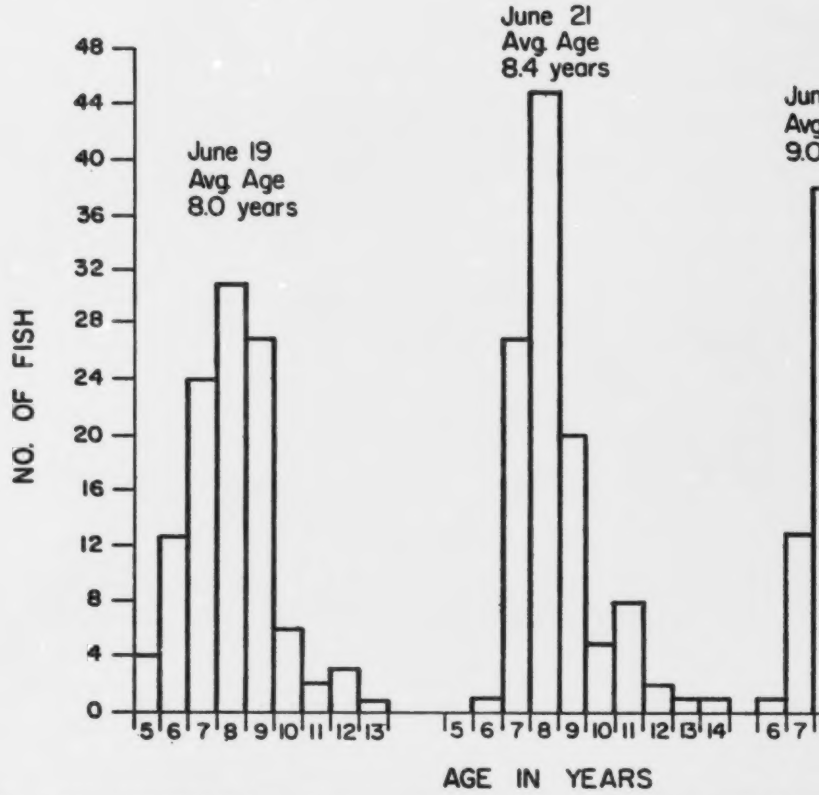


Figure 27. Age distribution for a random sample of commercially taken whitefish from Camp 3, Southern Indian Lake, summer fishery, 1973.

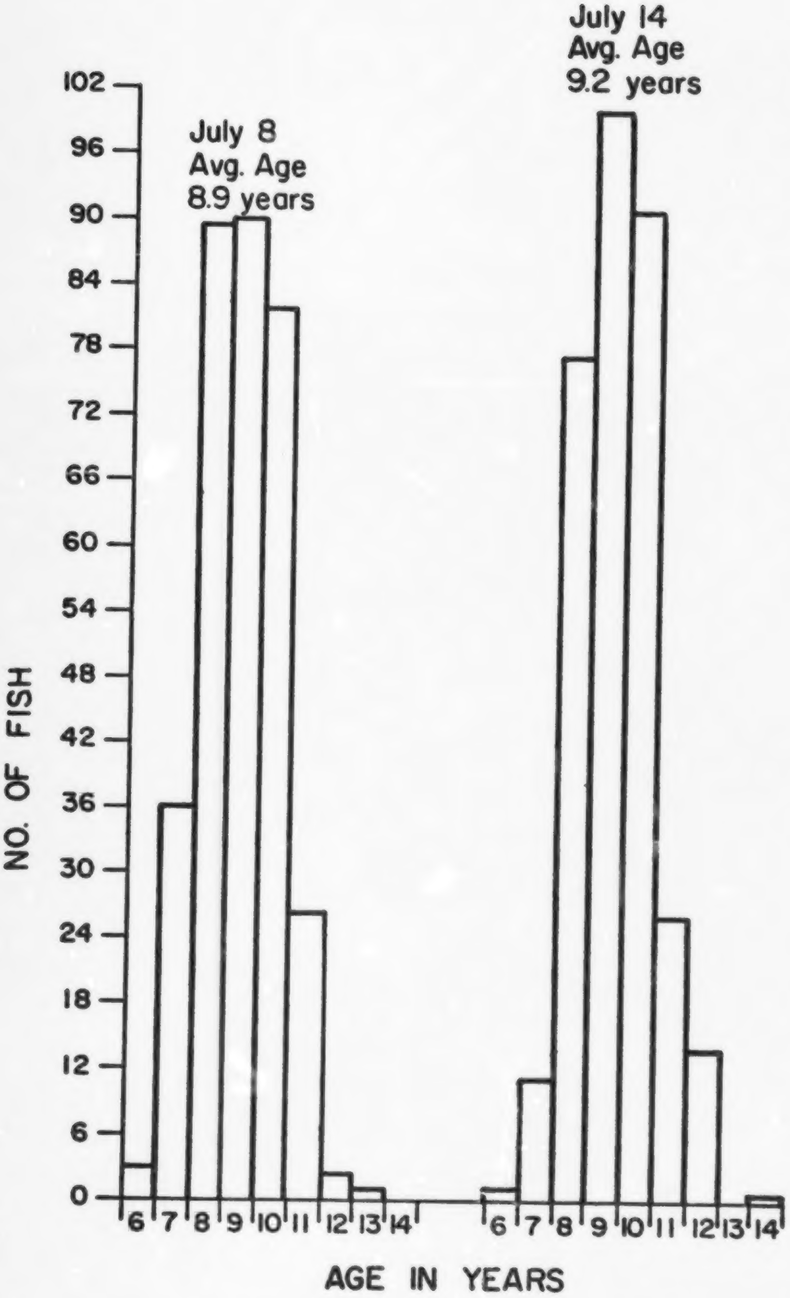


Figure 28. Age distribution for random samples of commercially taken whitefish from Loon Narrows, Southern Indian Lake, summer 1973.

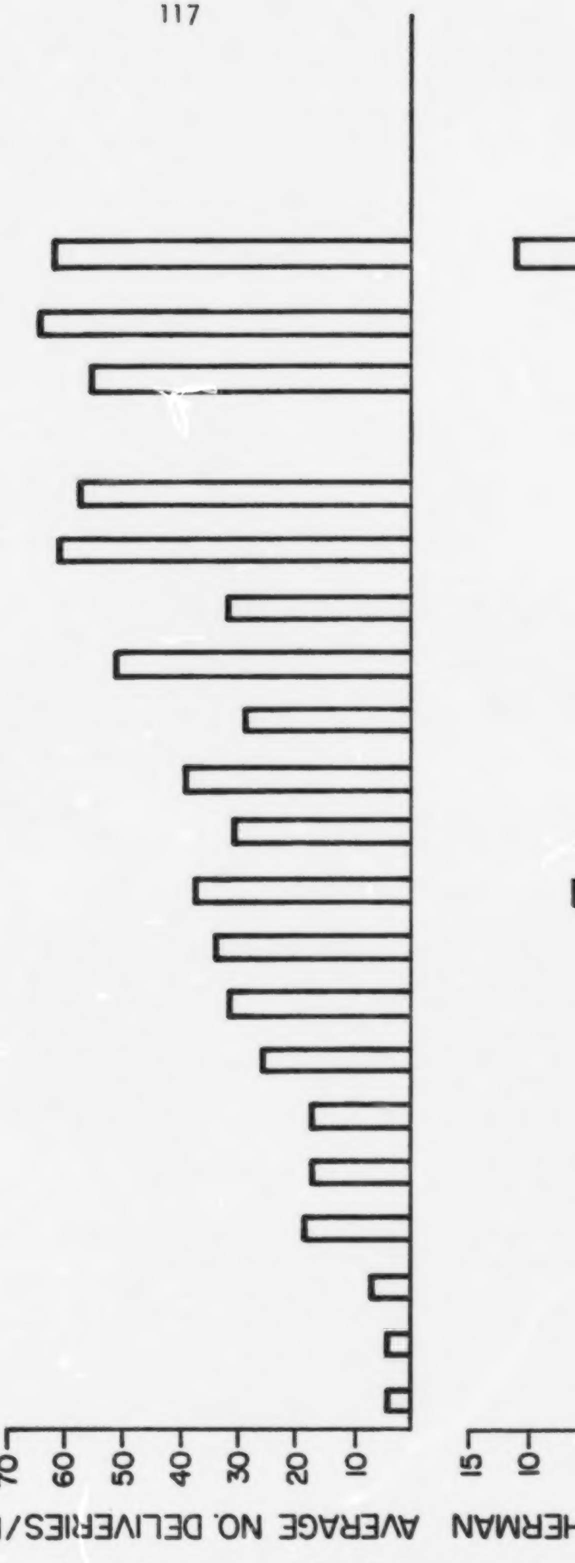


Figure 29. Distribution of landings among the fishermen and t
average number of landings/fisherman for the 1973
summer season on Southern Indian Lake.

and only 15 fishermen (24%) with catches under 5,000 lbs. This indicates that the fishermen are becoming more efficient.

The three classifications for fishermen used in the win fishery (Section 5.3.5.3) can also be applied to the summer fis During the summer season 24% could be classified as poor fisher 43% as average fishermen and 33% as excellent fishermen. The p fishermen averaged 8 deliveries/season, the average fishermen 3 deliveries/season and the excellent fishermen 57 deliveries/sea During the 1973 season there were 11 fishermen (17%) with landi over 20,000 lbs, the average number of deliveries/season of the fishermen was 61.

5.4.5.4 Weekly variations in summer fishery:

During the summer fishery there was no steady decline i production/week as witnessed during the winter fishery (Figure The summer production did vary considerably (4,363 lbs to 85,60 lbs), but these variations are very closely related to the eff (number of deliveries). The average production per delivery was 269 ± 65 lbs for Camp 3 and 381 ± 53 lbs for Loon Narrows. The average number of deliveries/week was 111.

5.4.5.5 Distribution of Effort:

During the summer fishing season the distribution of eff over the lake is centered around the three fish camps (Figure 21 At Camp 3 the effort is distributed mainly to the north and east with four areas of high production (Figure 21, Grid 25 K, 26 K,

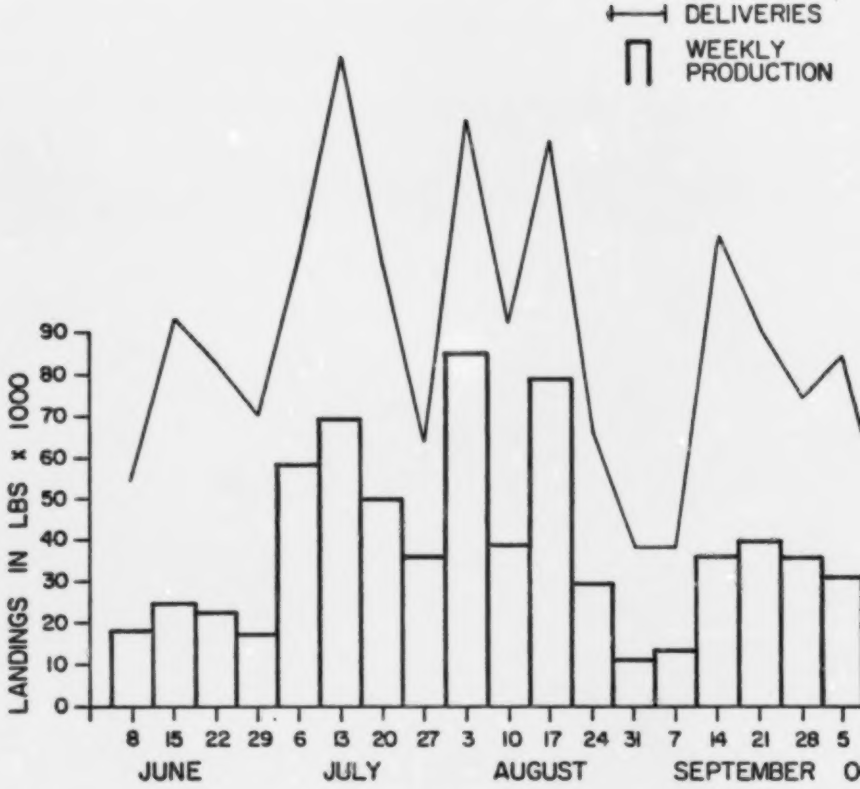


Figure 30. Total weekly production and total weekly deli
for the 1973 summer season on Southern Indian

28 P, 24 R, and 28 R). There were no high effort and production areas near Camp 9. At Loon Narrows high effort areas were to the north and east, with the large main basin of the lake having very high production and the area of interface between the waters of the extreme north end and waters of the main basin also having high production.

5.4.6 Revenue-Expenditure Analysis (Summer):

Appendix VII contains the revenue-expenditure analysis for summer fishing operations.

The diversity of fishing operations found in the winter fishery exists in the summer fishery as well. However, the primary difference in the summer operations is not in the transportation modes used but in the number of individuals within the enterprise. Twenty-eight of the 63 fishermen who made fish sales on Southern Indian Lake during the 1973 summer fishery were included in the survey. From these 28 fishermen, 18 enterprises were defined; 6 fishermen fished alone with no additional labor employed; 2 fishermen employed additional labor; 18 of the fishermen fished in pairs with no additional labor employed; finally, one pair of fishermen employed additional labor. Similar to the summary on the winter fishery, the unit cost of production, the daily wage rate, and the breakeven point are 3 calculations which illustrate these differences.

For the 6 fishermen fishing alone, the daily wage rate averaged $24 per man per day (range $10 - $56). The breakeven point averaged 5,263 lb. (range 2,684 - 6,982 lb). Unit costs of production for these enterprises averaged 6.82 ¢/lb. (range 4.83 ¢/lb. - 10.22 ¢/lb).

For the fishermen employing additional labor, the daily wage rates were $24 per man per day and $26 per man per day. Breakeven points were 9,477 lb. and 10,093 lb. respectively. The unit costs of production were 6.62 ¢/lb. and 9.26 ¢/lb.

The average daily wage rate for fishermen fishing in pairs was $21.50 per man per day. Breakeven points for these enterprises averaged 6,016 lb. (range 4,460 - 7,352 lb). Unit costs of production averaged 4.18 ¢/lb. (range 3.35 ¢/lb. - 5.99 ¢/lb.).

Finally, for the pair of fishermen employing additional labor, the daily wage rate was $15 per man per day. The breakeven point was 13,442 lb. while the unit cost of production was 7.97 ¢/lb.

5.4.7 Present state of summer fishery:

In recent years there has been a steady increase in summer production on Southern Indian Lake while the number of fishermen has decreased. This has led to a substantial increase in the average production per license. The summer production has never reached the present 800,000 lb quota but as in the winter fishery this is believed to be related to effort, not fish abundance. Although the analysis of the 1973 summer fishery is not completed, it appears safe to suggest the summer fishery is safe from overexploitation and could remain so even at a higher level of exploitation.

The general feeling among the fishermen is that fishing during the summer is easier and more profitable than in the winter, and this is shown in the differences between the summer and winter effort. Equipment used during the summer fishery also seems to be more durable than winter equipment, making the summer fishery more profitable.

5.5 IMPACT AND MITIGATION

5.5.1 Fish abundance:

Ayles (MS 1973) has outlined the impact of the diversion and flooding on the abundance of the three commercial species on Southern Indian Lake. In summary whitefish, walleye and northern pike should stabilize at population numbers lower than present.

As mentioned by Crooks (MS 1972) the pike population were much more prevalent in the commercial landings after flooding of Lac Seul, Ontario, and in recent years there has been a dramatic drop in the landings in all species. Crooks (MS 1972) suggested this may be related to the flooding and operation regime in the reservoir. As in some cases this decrease can not be related to decreased effort. The decrease began about 1961 after 32 years of flooding and regulations.

On Reindeer Lake the flooding and regulation has had limited effects on fish abundance. Doan (pers. comm.) suggested the Manitoba fishery has been maintained for the last 20 years (all after flooding) and the Saskatchewan fishery has improved as a result of the flooding.

The post-diversion situation on Southern Indian Lake is between both the above situations. It is larger than Lac Seul but smaller than Reindeer Lake. It will be raised more than Reindeer Lake but less than Lac Seul. The project could play havoc with many factors, most of which are related to spawning. A combination of the destruction of spawning beds and possible interference with migrations may tend to seriously retard recruitment and decrease fish abundance. There are no cases where the affect of the diversion of a river on fish populations has been monitored and therefore our predictive capabilities are limited.

5.5.2 Fishing methods:

The present fishing methods on Southern Indian Lake are described in Section 5.2. These are similar to the methods used in most of the northern Manitoba lakes. The most serious hazard to gillnets in reservoirs is debris either floating or sunken. There are, however, thriving fisheries in many reservoirs in the U.S.S.R. and Canada (Reindeer Lake and Lac Seul to name two).

People who have fished reservoirs have indicated that if gillnets are set within the confines of the original waterbody the problem of debris fouling is minimal (Burbour, pers. comm.). Doan (pers. comm.) indicated fishermen on Reindeer Lake were quick to locate and avoid areas where debris presented a problem.

On Southern Indian Lake the traditional fishing grounds are mostly in the deeper and more open stretches of the lake and if the fish remain in these areas after diversion there may be little problem caused by floating debris. Because the water level change will be in the area of 7-10 feet it is unlikely that people will have difficulty locating and avoiding the old shoreline when setting nets. Nets that do become entangled with debris will have to be written off and some compensatory action should be devised.

5.5.3 Fishing vs. alternative employment:

At least during the construction phase of the project there will be a number of jobs other than fishing available to the residents of Southern Indian Lake. If the trend evident in the past winter and summer continues there is likely to be a substantial reduction in the number of men participating in the fishery. Many of the poor and average fishermen are being attracted to other jobs. The average production per man for the fishery will tend to increase because of the absence of poor fishermen; however, the total production will drop. It is unlikely the remaining fishermen's catches will increase because most are fishing at the top of their productive capacity at present. It is difficult to predict whether these poor and average fishermen will return to the fishery after the construction phase of the program.

6. SPORT FISHING

6.1 Introduction:

To the sport fisherman the north has always been thought of as the land of trophy fish. This has drawn many tourists to northern Canada and in many cases has put considerable pressure on the fisheries. Pressure on northern sport fisheries was noticed as early as 1953 when Rawson and Atton (1953) noted that angling alone had contributed $400,000 to the economy of Lac La Ronge. In the past the cost of northern travel (usually air charter) limited northern sport fishing. With increase northern development, roads are gradually making areas available to more people for sport fishing.

There has never been an active sport fishing lodge on Southern Indian Lake or Opachuanau Lake. Presently sport fishing is limited to an area of the Churchill River near Leaf Rapids where the fishing pressure comes from the new community of Leaf Rapids, the Barrington River area where an American has a summer home and in the rest of the lake to the few tourists who pass through. None of the residents of Southern Indian Lake do any sport fishing.

6.2 Methods:

During the summer of 1972 the fisheries crews on Southern Indian Lake were encouraged to sport fish as much as possible and tabulate the results on the form shown in Appendix VI. The crews were supplied with spinning and spin-casting outfits and a good variety of spoons, plugs and hooks.

The data was summarized by calculating the fish per rod hour and average weight or length of all species. A total of 52.25 rod hours were fished producing 43 walleye and 111 pike.

Twenty sport fish species are recognized in Manitoba, 6 of which have been documented in Southern Indian Lake. They are whitefish, northern pike, walleye, sauger, perch and goldeye. Of these 6 species northern pike, walleye and sauger are the most sought after species.

6.3 Fishing success, summer 1972:

Almost anywhere on Southern Indian and Opachuanau Lakes one can angle, with success for northern pike. The average success rate for northern pike angling was 2.1 fish/rod hr., with an average length of 21.6 inches. The highest success rate was 5.5 fish/rod hr. and the largest northern pike angled was 20 lb (42.1 inches) (Plate 19). On June 27, 1971 a trophy size northern pike (over 18 lb) was caught on the Barrington River by V. Klingborg of Mesa, Arizona.

Walleye are more selective as to their habitat than northern pike. Although it was not uncommon to catch walleye in the lake they were more common at the mouth of rivers. The highest success rate for walleye was 9.5 fish/rod hr. with an average weight of 22 oz. (Plate 20). No trophy size walleye (over 8 lb)

Plate 19. Two large northern pike from Southern Indian Lake, on the right 10 lb. 6 oz.; on the left 21 lb. 4 oz.

Plate 20. A typical walleye catch angled on Southern Indian Lake average weight 1 lb. 6 oz.

were either angled or netted on either lake. Only walleye and northern pike were caught while angling on the lakes.

Extreme differences were noted for individuals over the season. For some of the people it was their first time angling. There were also several times when no fish were caught even after angling for extended periods. Much of the 52.25 hours angled were done randomly and not in habitat common to either species. All the above suggest that fishing success on the lake could even be higher. When good pike habitat was fished very high catches were recorded (4.0 to 5.5 fish/rod hr.) and pike as large as 12 lb were not uncommon. Walleye from the area are not large (usually less than 3 lbs) but are very numerous in several areas. The success rate of 9.5 fish/rod hr was not felt to be biased and similar fishing should be available at the 8 major spawning streams on the lake (this particular success rate was on stream #48).

6.4 Potential for sport fishing:

There is a very high potential for trophy northern pike fishing on Southern Indian and Opachuanau Lakes. The pike production is excellent and good habitat is readily available in all parts of the lake. The pike are not only large but very numerous which is also attractive to the sport fishermen.

The potential of the walleye sport fishery is limited by the remoteness of many of the better areas and the smaller size of the fish. Although walleye may not constitute the main reason to sport fish in the area, it offers an attractive alternative for those who might come seeking pike.

6.5 Comparison with other areas:

Underwood and McLellan (1970) did a comparison of gill net fishing effort on several northern lakes with sport fisheries and Southern Indian Lake (data from McTavish, 1952). Underwood and McLellan (loc. cit.) concluded from their comparison that SIL had the potential to be better for trophy pike than Reed Lake which at that time was the major trophy pike lake in Manitoba. From the data reported by Ayles (MS, 1973) the average number of pike/100 yds of gill nets (all meshes) on SIL was 8.5 and for walleye 11.4. These figures are higher than those of McTavish (loc. cit.). This data shows the potential for sport fishing to be even higher.

6.6 Mitigation:

The road system which is being developed in connection wit the Hydro scheme will help the sport fishery on Southern Indian and Opachuanau Lakes to realize its full potential. As mentioned earlier sport fishing in many northern areas is not pursued to its full potential because of the lack of cheap transportation facilities.

The raise in level on Opachuanau Lake, after diversion, will be in the order of 2 feet. Shortly, Leaf Rapids will be connected to Thompson and the south by an all-weather road. If a sport fishery is to be promoted and developed small-craft landing sites and boat ramps should be constructed in the Leaf Rapids a of the Churchill River. If tourism and sport fishing are of any concern the entire shoreline of Opachuanau Lake and the Churchil River should be cleared to the high water mark. These two measu combined with the high sport fishing potential, and the post-diversion availability of trophy northern pike could make this area a mecca for sport fishermen. The controlled access to the area would make the management of the fishery very easy and a sustained yield could be maintained.

7. SUMMARY

1) The youngest mature whitefish male was VII and youngest mature female was VI; the shortest mature males a females were 340 to 349 mm.

2) There is evidence to suggest mature females do spawn every year.

3) The average number of eggs per female was 28,6 there was on the average 26,883 eggs/kg of body weight.

4) Ripe females were taken most abundantly at a d 1.5-2.5 meters but were found at depths of up to 6.75 mete

5) The preferred substrate for spawning was bould large broken rock.

6) Whitefish spawning activity began when the wat perature fell to 3°C and reached a peak when the temperatu to 2°C. After 2°C for 4 days 80% of the mature fish nette spent.

7) There appear to be extensive migrations of whi from areas south of Long Point to areas north of Long Poin prior to spawning in September.

8) The walleye spawning run began (gravid females found) when water temperatures were 12°C. The run was sti progress when water temperatures were above 17°C.

9) The youngest mature male and female walleye we

10) Male walleye enter the streams prior to females and after spawning spent individuals tend to move upstream before returning to the lake.

11) During July the walleye move back into the main lake and by August are randomly dispersed.

12) The hours of highest activity for walleye during spawning is from 24:00 to 08:00.

13) Substrate on spawning grounds was cobble (6" to 24" in diameter) interspersed with gravel.

14) There was an average of 46,634 eggs/female and 42 eggs/gm of body weight.

15) Eight major spawning areas were found on Southern Indian Lake, they were Barrington River, Barlow Lake drainage, McLeod Lake drainage, Muskwesi River, Waddie River, Sandhill Bay, Cousin's Lake drainage, and the tributaries of the Churchill River upstream of Opachuanau Lake.

16) Since the winter fishery began in 1941-42 there have been as many as 10 fish buyers on the lake.

17) These buyers maintained as many as 18 fish camps on the lake.

18) At present all fish are bought by the Southern Indian Lake Co-op Fisheries Ltd.

19) The highest winter production was 932,800 lb in 1946-47 and the lowest 20,600 lb in 1941-42. The average winter

production is 455,626 lb.

20) Whitefish make up an average of 95.4% of the winter production, walleye 3.9%, and pike 0.7%.

21) Decreased winter production in recent years is believed to be related to decreased effort.

22) The average gross income per fisherman has increased from $507 during the period 1946-1951 to $1,133 during the period of 1966-1971.

23) Winter transportation of fish has been accomplished by anything from "cat-swing" to aircraft and at present there is a trend to aircraft because of the high maintenance costs on Bombardiers.

24) The average production per license for the 1972-73 season (6,438 lb) was higher than the preceeding year and also higher than the 1966-1971 average.

25) The average catch/unit of effort during the 1972-73 season was 44 lb/net/night (a net was 100 yds long by 40 meshes deep and 5 1/4" mesh) and varied from 14 lb/net/night to 217 lb/net/night.

26) The average of whitefish from the winter commercial fishery in 1972-73 was 8.7 years with VIII, XI and X being the dominant year classes.

27) Whitefish mortality for the Age X - XIII fish was 73%.

28) Fishermen on Southern Indian Lake during the 1972-73

winter season could be divided into 3 groups; those producing less than 5,000 lb, those producing between 5,000 and 13,000 lb and those producing more than 13,000 lb.

29) Fishermen in the first group (above) had fewer deliveries and lower c.u.e. than the other groups.

30) Forty-six percent of the fishermen were in both of the first two groups and 8% were in the third group.

31) The gradual decline in weekly landings as the winter season progressed was believed to be due to increased fish movement and not reduction in the stocks.

32) Seventy-three percent of the fishermen earned less than $1,500 during the 1972-73 winter season as compared to 88% in 1971-72 and 96% in 1970-71.

33) The breakeven analysis indicated the daily wage rate using a dog team ranged from $16 to $32 with production costs from 5.89¢ to 6.73¢/lb.

34) The daily wage rate using a Bombardier were from $21.50 to $47.00 with production costs from 6.62¢ to 11.01 ¢/lb.

35) The average landings for the summer season since it began in 1950 has been 429,988 lb with a range of 195,800 lb (1950) to 712,900 lb (1972).

36) The summer production averaged 86% whitefish, 13% walleye and 1% pike and goldeye. Goldeye have not been marketed since 1967 and are very scarce in the lake.

37) The value to the fishermen for the summer fishery increased from \$9,790 in the 1950 season to \$149,807 in the 1972 season.

38) Summer fish transportation has changed from air to rail to Winnipeg to boat, truck and rail with a substantial decrease in costs.

39) The average production/license for the 1973 summer season was 11,509 lbs/license.

40) The average catch per unit of effort for the summer season at Camp 3, Camp 9 and Loon Narrows, was 36, 26 and 51 lbs/net/24 hrs respectively.

41) The summer commercial fishery at Camp 3 cropped mainly VII to IX year whitefish. The summer commercial fishery at Loon Narrows cropped mainly VIII to X year whitefish.

42) During the 1973 summer fishery 33% of the fishermen produced over 13,000 lb, 43% produced from 5,000 to 13,000 lbs and 24% produced less than 5,000 lbs.

43) Weekly variations in landings during the summer fishery were directly related to effort.

44) The average weight per delivery at Camp 3 for the summer fishery was 269 ± 65 lbs and 381 ± 53 lbs at Loon Narrows.

45) For the summer fishery the average daily wage rate was from \$15 to \$26/day with production costs from 3.35¢ to 10.22 ¢/lb.

46) After flooding and diversion fish populations should stabilize at slightly lower levels than at present.

47) If the fish remain in the present fishing grounds the traditional fishing methods will continue to be successful.

48) The average success rate for sport fishing for northern pike on Southern Indian Lake was 2.1 fish/rod hour and the average length was 21.6 inches.

49) The highest success rate was 5.5 fish/rod hour with the largest angled pike being 20 lb and 42.1 inches long.

50) The highest success rate for walleye angling was 9.5 fish/rod hour with an average weight of 22 ozs.

51) The potential of the trophy northern pike fishery on the lake is excellent.

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Barbour, G. Fisheries Biologist, Dept. of Environment, Fisheries Service, St. John's, Nfld.

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Appendix I. Summary of data from whitefish spawning study, Loon Narrows, Southern Indian Lake.

Date	Site	Depth (m)	Water Temp. (°C)	Total Males	Mature Males	% Males Spent	Total Females	Mature Females	% Females Spent
Sept 22/72	1	9.1	5	5	1	0	7	1	0
	2	2.6	5	0	0	0	2	0	0
	3	2.1	5	0	0	0	1	0	0
	4	2.8	5	3	0	0	7	0	0
Sept 23/72	5	3.5	5	2	2	0	3	0	0
	6	1.3	5	0	0	0	1	0	0
	7	3.2	5	11	2	0	4	0	0
Sept 25/72	8	5.7	5	8	2	0	9	1	0
	9	7.2	5	11	6	0	31	5	0
	10	6.0	5	7	1	0	6	1	0
Sept 26/72	11	7.4	5	6	3	0	13	3	0
Sept 27/72	12	8.3	5	9	2	0	9	0	0
	13	6.8	5	8	5	0	5	2	0
Sept 28/72	14	3.9	4.5	6	5	0	9	1	0
	15	5.0	4.5	1	1	0	7	1	0
Sept 29/72	16	7.0	4	6	2	0	11	3	0
	17	18.0	4	6	0	0	12	1	0

Appendix I. (cont'd)

Date	Site	Depth (m)	Water Temp. (°C)	Total Males	Mature Males	% Males Spent	Total Females	Mature Females	% Females Spent
Oct 1/72	18	2.1	4	19	12	0	19	11	18
	19	2.2	4	7	6	16	9	5	60
Oct 2/72	20	5.1	3.5	53	24	50	37	16	43
	21	1.4	3.5	23	11	18	42	20	24
Oct 6/72	22	3.7	3	9	8	0	5	4	25
	23	0.7	3	11	7	14	24	14	57
Oct 7/72	24	2.1	2.5	21	8	50	24	11	81
	25	2.5	2.5	10	4	25	5	3	100
Oct 8/72	26	2.2	2.0	31	9	77	29	9	100
	27	1.5	2.0	11	10	30	18	8	37
Oct 10/72	28	1.5	2.0	37	27	51	32	21	80
	29	7.0	2.0	32	10	90	65	6	83

Appendix II. Summary of data from other walleye spawning study, McBride River.

Date	Site	Water Temp. (°F)	Total Males	Mature Males	% Males Spent	Total Females	Mature Females	% Females Spent
May 22/73	1	-	21	20	0	6	5	0
	2	54	13	13	0	9	7	0
	3	-	29	26	0	9	3	0
May 23/73	4	-	18	15	0	8	5	0
	5	63	12	12	0	6	4	0
	6	-	7	6	0	10	5	60
May 24/73	7	-	3	3	0	0	0	0
	8	-	2	2	0	4	3	0
May 25/73	9	54	57	56	0	14	13	15
	10	62	5	5	0	11	11	10
	11	60	13	11	0	6	2	50
	12	-	1	1	0	1	1	100
May 26/73	13	-	9	8	0	7	5	40
	14	59	11	11	0	3	3	33
	15	58	5	5	0	9	4	50
	16	-	4	4	25	4	4	50
May 27/73	17	62	24	24	4	9	6	33
	18	62	16	16	0	14	12	33
	19	63	14	10	0	10	7	42

Appendix II. (cont'd)

Date	Site	Water Temp. (°F)	Total Males	Mature Males	% Males Spent	Total Females	Mature Females	% Females Spent
May 28/73*	21	-	13	13	8	6	4	24
	22	-	18	17	6	6	6	66
	23	-	2	2	0	3	2	50
	24	-	2	2	0	1	1	100
	25	0	2	1	0	1	0	0
	26	-	1	1	0	2	0	0
	27	-	12	12	33	7	3	100
May 29/73*	28	-	14	14	50	10	6	83
	29	-	9	7	0	2	0	0
	30	-	1	1	0	0	0	0
	31	-	2	0	0	3	0	0
	32	-	3	3	33	4	1	0

* Sites 21-32 were part of a 48-hour study of diurnal movement patterns.

Appendix III. Summary of data from the walleye spawning study, Muskwesi River.

Date	Site	Water Temp. (°F)	Total Males	Mature Males	% Males Spent	Total Females	Mature Females	% Females Spent
June 2/73	1	-	2	2	100	1	1	100
	2	-	1	1	0	2	2	100
	3	-	0	0	0	4	4	100
	4	-	4	4	75	6	6	83
June 3/73	5	58	4	4	100	4	4	100
	6	58	0	0	0	3	3	100
	7	58	1	0	0	4	4	100
June 4/73	8	57	2	2	100	3	3	100
	9	56	3	3	100	4	3	66
June 5/73	10	56	0	0	0	0	0	0
	11	54	3	3	100	4	4	100
June 6/73	12	48	0	0	0	1	1	0
	13	48	0	0	0	1	1	100
June 7/73	14	49	0	0	0	0	0	0
	15	49	0	0	0	2	1	100
June 8/73	16	-	0	1	100	0	0	0
	17	-	2	2	100	2	2	100

Appendix IV. Summary of the walleye caught during the synoptic survey May and June, 1973.

Date	Stream No.	Water Temp.	Total Males	Total Females
May 22	105	13	0	0
	101	51	0	0
	106A	48	0	0
	106A1	-	0	0
May 23	111	13	22	2
	111	13	0	0
	4	13	7	1
	7	14	0	0
	110	10	0	1
May 24	1	14	43	11
	111	14	29	4
	11	9	66	14
May 27	12	15	0	1
	19	13	0	0
	21	12	8	1
	23	14	2	0
May 28	29	14	0	0
	108	12	0	0
	107	13	0	0
May 29/73	99	13	1	3
	97	12	6	0
	91	14	0	0
	91B	16	0	0
May 30/73	44	15	0	0
	42	15	1	0
	38	17	1	0
June 1	48	15	1	0
	45	15	0	0
June 2	52	15	0	1
	54	13	0	0
	58	14	0	0
	61	14	0	0

Appendix IV. (cont'd)

Date	Stream No.	Water Temp.	Total Males	Total Females
June 3	63	16	0	0
	73	15	0	0
	76	15	0	0
	80	15	0	0

Appendix V. Summary of seasons, quotas, etc., for the winter seasons on SIL since 1940-41.

Date	Area	Quota (lb)	Species	Season	Nets/man	Mesh	No. of licenses	Cost	Preference
1940-41	Lake	60,000	whitefish & trout	Jan 8 - March 8	2,000 yd	5¼	?	10.00	
1941-42	Lake	200,000	whitefish & trout	3rd Mon. 2nd Sat. Nov.-Mar.	?	?	15		
1942-43	Lake	200,000	whitefish & trout	3rd Mon Nov. - March 31	?	?	15		
1943-44	Lake	200,000	whitefish & trout	3rd Mon Nov. - March 31	?	?	15		

For the winter seasons above only men having special agreements with Mr. Thomas Lamb were given licenses. This was a concession to Lamb for building a winter road to the lake at no cost to the government.

Jan 22, 1945	Lake	400,000	whitefish & trout	3rd Mon. Last Sat. Nov.-Mar.	?	5¼	?	?	Residents of district
June 27, 1947	Lake	800,000	whitefish & pickerel	3rd Mon. Nov. - March 15	1,000 yd	5¼	100	10.00	Residents of district limit of 800 lb/license

Appendix V. (cont'd)

Date	Area	Quota (lb.)	Species	Season	Nets/man	Mesh	No. of licenses	Cost	Preference
Oct 30, 1947	Lake	600,000	whitefish & pickerel	3rd Mon. Nov. - March 15	1,000 yd	5¼	50 10	10.00	Residents of district who held licenses in 46/47. Limit of 1,200 lb/license
Oct 5, 1948	Lake	800,000	whitefish & pickerel	3rd Mon. Nov. - March 15	1,000 yd	5¼	100	10.00	Residents of district who held licenses in 46/47. Limit of 8,000 lb/license
Oct 12, 1949	Lake	800,000	whitefish & pickerel	Dec 12 - March 15	1,000 yd	5¼	90 10	10.00	SIL & NH Moose & Cormonant L.
1950	Lake	625,000	whitefish & pickerel	3rd Mon. Nov. - March 15	1,000 yd	5¼	80	10.00	SIL & NH
1951	Lake	600,000	whitefish & pickerel	Dec 15 - March 31	1,500 yd	5¼	80	10.00	SIL & NH +20 outsiders

Appendix V. (cont'd)

Date	Area	Quota (lb.)	Species	Season	Nets/man	Mesh	No. of licenses	Cost	Preference
Nov 17, 1952	Lake	600,000	whitefish & pickerel	3rd Mon. Nov. - March 31	1,500 yd	5¼	80	10.00	?
Nov 16, 1956	Lake	600,000	whitefish & pickerel	3rd Mon. Nov. - March 31	1,500 yd	5¼	100	10.00	Residents of District
Oct 10, 1957	Lake	500,000	whitefish & pickerel	3rd Mon. Nov. - March 31	1,500 yd	5¼	100	10.00	Residents of District
Oct 17, 1958	South Bay	50,000	whitefish & pickerel	3rd Mon. Nov. - March 31	1,500 yd	5¼	?	10.00	S.I.L.V.
Oct 14, 1959	Lake	300,000	whitefish & pickerel	3rd Mon. Nov. - March 31	1,500 yd	5¼	100	10.00	Residents of District
Oct 25, 1960	Lake	500,000	whitefish & pickerel	Jan 1 - March 31	1,500 yd	5¼	100	10.00	Residents of District
Aug 24, 1961	South Bay	50,000	whitefish & pickerel	Nov. 1 - April 15	1,500 yd	5¼	?	10.00	S.I.L.V.

Appendix V. (cont'd)

Date	Area	Quota (lb.)	Species	Season	Nets/man	Mesh	No. of licenses	Cost	Preference
Aug 31, 1961	Lake	500,000	whitefish & pickerel	Jan 1 - March 24	1,500 yd	5½	80 5	10.00	S.I.L.V. outsiders
Sept 12, 1962	South Bay	50,000	whitefish & pickerel	Nov. 1 - April 15	1,500 yd	5½	?	10.00	S.I.L.V.
Oct 15, 1962	Lake	600,000	whitefish & pickerel	Jan 1 - April 15	1,500 yd	5½	75 5	10.00	S.I.L.V. outsiders
Sept 25, 1963	South Bay	50,000	whitefish & pickerel	Nov 1 - April 15	1,500 yd	5½	?	10.00	S.I.L.V.
Dec 31, 1963	Lake	600,000	whitefish & pickerel	Feb 1 - April 15	1,500 yd	5½	75 5	10.00	S.I.L.V. outsiders
1964-64	Lake & South Bay same as '63-64.								
1965-66 & 1966-67	Lake & South Bay same as '63-64.								
May 11, 1967	Lake	600,000	whitefish & pickerel	Jan 15 - April 15	1,500 yd	5½	75 5	10.00	S.I.L.V. outsiders
May 9, 1968	same as May 11, 1967.								

Appendix V. (cont'd)

Date	Area	Quota (lb.)	Species	Season	Nets/man	Mesh	No. of licenses	Cost	Preference
April 30, 1969	same as May 11, 1967.								
June 8, 1971	Lake	400,000	whitefish & pickerel	Jan 15 - April 15	1,500 yd	5½	?	10.00	S.I.L.V.

SIL - Southern Indian Lake

NH - Nelson House

S.I.L.V. - South Indian Lake (village)

Appendix VI. Summary of seasons, quotas, etc. for the summer seasons on SIL since 1950.

Date	Area	Quota (lb.)	Species	Season	Nets/man (yd)	Mesh ('')	No. of licenses	Cost of licenses	Preference
1950	Lake*	150,000 (increased to 175,000)	whitefish & pickerel	2nd Mon - Aug; 3rd Sat Sept	?	?	25	?	Bonafide SID
Mar 13, 1953	Lake	200,000	whitefish & pickerel	3rd Mon - Aug; 3rd Sat Sept	1,500 yd	5¼	25	10.00	Bonafide SID
1953	South Bay	50,000 (experimental)	whitefish & pickerel	1st Mon - June; 2nd Sat July	500 yd	4¼	?	10.00	Bonafide SID
Feb 9, 1954	South Bay	50,000 (experimental)	whitefish & pickerel	1st Mon - June; 2nd Sat July	1,500 yd	4¼	?	10.00	Bonafide SID
1956	Lake			Season extended to Sept. 22.					
Sept 3, 1957	Lake	Additional 100,000 lb in summer to be deducted from winter.							
Aug 17, 1958	Lake	Additional 50,000 lb in summer to be deducted from winter.							
May 1, 1959	Lake	250,000	whitefish & pickerel	3rd Mon - Aug; 3rd Mon Sept	1,500 yd	5¼	25 5	10.00	Res of SILV Outside supervisors

Appendix VI. (cont'd)

Date	Area	Quota (lb.)	Species	Season	Nets/man (yd)	Mesh (")	No. of licenses	Cost of licenses	Preference
Sept 7, 1959	Lake	200,000 lb transferred from winter season and season extended to Sept. 30.							
Apr 22, 1960	Lake	300,000	Rest same as May 1, 1959						
Feb 16, 1961	Recinds previous orders								
Feb 16, 1961	Lake	300,000	whitefish & pickerel	Sept 1 - Oct 20	1,500 yd	5½	?	10.00	Residents SILV
Feb 16, 1961	South Bay	50,000	whitefish & pickerel	June 1 - Oct 20	1,500 yd	4½	?	10.00	Residents SILV
Apr 20, 1961	North of 57° 31'	100,000	whitefish & pickerel	June 1 - Oct 20	1,500 yd	4½	?	10.00	Residents SILV
May 1, 1962	Recinds previous orders								
May 10, 1962	South Bay	50,000	whitefish & pickerel	June 1 - Oct 20	1,500 yd	4½	?	10.00	Residents SILV
May 10, 1962	Lake	300,000	whitefish & pickerel	Sept 1 - Oct 20	1,500 yd	5½	?	10.00	Residents SILV
May 10, 1962	North Bay	100,000	whitefish & pickerel	June 1 Oct 20	1,500 yd	5½	?	10.00	Residents SILV

Appendix VI. (cont'd)

Date	Area	Quota (lb.)	Species	Season	Nets/man (yd)	Mesh (")	No. of licenses	Cost of licenses	Preference
May 26, 1966	57°30' N 98°20' W	175,000	whitefish & pickerel	June 1 - Aug 21	1,500 yd	4½	30	10.00	Residents SILV
July 27, 1966	57°30' N 98°20' W	Increased to 225,000	whitefish & pickerel	June 1 - Aug 21	1,500 yd	4½	30	10.00	Residents SILV
May 26, 1966	Bigami Bay	50,000	whitefish & pickerel	June 1 - Aug 21	1,500 yd	4½	10	10.00	Residents SILV
May 26, 1966	56°42' N 99°00' W	30,000	whitefish & pickerel	June 1 - Aug 21	1,500 yd	4½	5	10.00	Residents SILV
May 26, 1966	Lake	300,000	whitefish & pickerel	Sept 1 - Oct 20	1,500 yd	5½	50	10.00	Residents SILV
Aug 24, 1966	Lake	300,000	whitefish & pickerel	opens Aug 25, 66	1,500 yd	5½	50	10.00	Residents SILV
May 11, 1967	57°30' N 98°20' W	225,000	whitefish & pickerel	June 1 - Aug 21	1,500 yd	4½	35	10.00	Residents SILV
May 11, 1967	Bigami Bay	50,000	whitefish & pickerel	June 1 - Aug 21	1,500 yd	4½	10	10.00	Residents SILV
May 11, 1967	56°42' 90°00'	30,000	whitefish & pickerel	June 1 - Aug 21	1,500 yd	4½	5	10.00	Residents SILV

Appendix VI. (cont'd)

Date	Area	Quota (lb.)	Species	Season	Nets/man (yd)	Mesh (")	No. of licenses	Cost of licenses	Preference
May 11, 1967	Lake	300,000	whitefish & pickerel	Sept 1 - Oct 20	1,500 yd	5¼	50	10.00	Residents SILV
May 9, 1968	Lake	300,000	whitefish & pickerel	Aug 20 - Oct 20	1,500 yd	5¼	50	10.00	Residents SILV
May 9, 1968	All other areas the same as May 11, 1967								
Apr 30, 1969	All areas same as May 11, 1967 except lake opens on Aug. 15 instead of Sept. 1.								
June 8, 1971	entire lake	800,000	whitefish & pickerel	June 1 - Oct 1	1,500 yd	5¼	?	10.00	Residents SILV

SID - Southern Indian Lake District

S.I.L.V. - South Indian Lake (village)

APPENDIX VII

Revenue-Expenditure Analysis for Selected Fishing Operations on Southern Indian Lake

by

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Environment Canada
Fisheries and Marine Service
Economics Branch, Central Region

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CHAPTER 1

STUDY OBJECTIVES AND METHODS

1.1 Introduction:

In August, 1971 Canada and the Province of Manitoba agreed to a set of studies the purpose of which was

> "to determine the effects that regulation of Lake Winnipeg, diversion from the Churchill River and development of hydro-electric potential of the Churchill River diversion route are likely to have on other water and related resource uses and to make recommendations for enhancing the overall benefits with due consideration for the protection of the environment."[1]

Given the specific terms of reference detailed in the main report, the Multiple Water Use Section, Resource Management Branch, Fisheries and Marine Service commenced investigations of fish production in the spring of 1972. Intuitively, it was not feasible to assess fish production without also examining the economics of fish production. To illustrate, fish production is a function not only of the availability of fish but also of numerous economic factors such as the prices for fish, the costs of inputs to the production process, and the availability of alternative employment. The data available for an economic analysis of the fisheries in the study area was found to be very limited, essentially consisting of the catch statistics, landed value of catch, and the count of the number of licenses issued each fishing season. With the advent

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1. p. 3. Canada-Manitoba Study for Lake Winnipeg and the Churchill and Nelson Rivers.

of the Freshwater Fish Marketing Corporation (FFMC) and the resulting centralized source of information, it became possible to analyze the distribution of income amongst fishermen. An analysis of these data for the fisheries affected by hydro development shows that gross returns from fishing in many of the fisheries are very low. However, no analysis of the viability of fishing operations in the northern portions of the study area has been made. To provide basic economic information which would be of use in the assessment of fish production, the Economics Branch, Fisheries and Marine Service, Central Region, agreed to undertake revenue-expenditure surveys for the 1973 winter and 1973 summer commercial fisheries on Southern Indian Lake.

1.2 Survey procedure:

For the winter fishery, the Resource Management Branch stationed a technician on the lake to collect biological data. In addition, cost data were collected through interviews with fishermen. Of the 37 individuals who made fish sales to the agent of the FFMC, 11 fishermen were interviewed.

For the summer fishery, data were collected in a similar manner. Of the 65 individuals who made fish sales to the agent of the FFMC, 28 fishermen were interviewed.

1.3 Analytic framework:

Fishermen revenues are the sum of fish sales plus miscellaneous revenues. For the entire fishery, revenues from fish sales are calculated from the FFMC fisherman weighbill.

The total cost of production is defined to be the sum of fixed and variable costs. Variable costs are those costs which change directly according to the amount of fishing effort and include such items as the costs of labor employed, fuel and lubrication, transport, provisions, etc. Fixed costs include those costs necessary to maintai the physical and financial investment in an enterprise and include suc items as depreciation and interest on capital equipment.

Operating profit, probably the measure of performance used by fishermen, is the difference between total revenue and variable cost.

The difference between total revenue and total cost is net earnings (before tax). Included in this amount are the return to lab and the amount necessary to pay taxes.

If the latter amount is neglected, an estimate of the daily wa rate from fishing can be made if the net earnings per individual is divided by the number of days participation in the fishery. Man days participation will equal the sum of the days spent fishing, the days preparing before the season, and the days spent cleaning up after the end of the season.

The breakeven point is that level of production at which total revenue equals total cost. For the enterprises studied, the breakeve points calculated are underestimated since no return to labor for the "owner-operator" enters the cost equation.

CHAPTER 2

WINTER FISHERY

2.1 Description of winter fishery:

Southern Indian Lake was first commercially fished in the winter season of 1941-42. From that time to the formation of the FFMC in 1969, at least 8 fish dealers operated on the lake. Usually the dealer acted as both fish dealer and as outfitter for fishing operations. With the formation of the FFMC as the sole buyer and seller of the fishery product, the individual fish dealers were replaced by the Southern Indian Lake Fishermen's Cooperative which was designated agent of the FFMC for the surrounding area.

Production in the winter fishery has ranged from a low of 20,600 lb during the initial year of the fishery to a high of 932,800 lb in 1946-47. Whitefish continues to be the major commercial specie, accounting for an average of 95% of the commercial catch. The catch statistics for the 30 years the lake has been winter fished are summarized in Figures 14, 16, and Appendix V of the main report. Statistics for the recent years of the fishery, derived from the FFMC weighbill, are summarized in Table 1.

2.2 Operation of winter fishery:

The type of gear used in fishing operations is restricted to gillnets; the maximum yardage per license is 1,500 yd. If the 1973 winter fishery is representative, few fishermen fish the maximum yardage

Table 1. Landings, landed value, average price(winter fishery 1971-73 inclusive).

Season	Winter 1973	Winter 1972	Winter 1971
Weight (round equivalent)	289,766 lb	290,358 lb	174,739 lb
Landed value	$40,784	$33,403	$27,214
Average price	14.1 ¢/lb	11.5 ¢/lb	15.6 ¢/lb

Source: Economics Branch records of fish sales to the FFMC allowed. The pattern of production is such that the duration of the set is 2 or 3 nights with the same gang of nets lifted every second or third day. Once the nets are set they generally are not moved over the remainder of the season. Transportation modes used range from dog teams to bombardiers. If dog teams are used, alternate arrangements are made to haul fish from the nets to the fish station when catches are heavy. For the 1973 winter fishery, the cooperative provided this service at 2¢ per pound of fish. A faster means of transport with greater capacity to haul fish is provided by the skidoo; problems are encountered with the frequency of breakdown under current operating conditions. The bombardier is also used on the lake, but the frequency of breakdown is even more of a problem. It is not uncommon that both skidoo and bombardier be utilized by an enterprise over the course of the season.

The agency operation for the winter fishery is provided by the cooperative using the fish stations at Loon Narrows and Leaf Rapids. The major fishing area in winter is Loon Narrows and fishermen are paid F.O.B. this station. Once the fishermen has delivered his catch to Loon Narrows, the fish are graded, weighed, iced, and packed in tubs to be shipped to the Leaf Rapids plant. Over the course of the 1973 winter fishery, both bombardier (transport rate 5¢/lb) and chartered aircraft (transport rate 6.5¢/lb) were used to deliver fish from Loon Narrows to Leaf Rapids. The frequency of breakdown of the bombardier and the resultant economic losses through the deterioration of fish soon eliminated it as an economic alternative to air transport. Once the fish has been delivered to Leaf Rapids, the fish is re-iced, re-packed, and stored for shipment to Lynn

Lake. That delivery is made using the cooperative truck. The rail service from Lynn Lake to Winnipeg (agent transport allowance 4.5¢/l fish) provides the final link in the distribution of fish from lakesi to the FFMC plant in Transcona.

2.3 Analysis of gross earnings from winter fishery:

The distribution of gross revenue amongst fishermen for the wi seasons 1971-73 inclusive is summarized in Table 2. For the 1973 wi fishery 73% of the fishermen who sold fish to the FFMC earned less t $1,500. In the previous winter fishery 88% earned less than $1,500 in the 1971 fishery 96% received less than $1,500.

The information on the number of deliveries per fisherman, derived from the FFMC fishermen weighbill, shows the direct relation between effort (measured in deliveries) and gross revenue. The anal of the number of deliveries by income interval is summarized in Tabl

2.4 Revenue - Expenditure analysis (dog teams):

Dog teams were used by 4 of the 11 fishermen who participated the survey. These 4 fishermen grouped into 2 enterprises with the f in each enterprise entering revenue-cost sharing arrangements. The revenue-expenditure analysis for these enterprises is detailed in Ta and Table 5.

A comparison of the revenues and expenditures of the two ente shows that items of expenditure were essentially identical. Variabl costs consisted of expenditures on freight to Loon Narrows plus

Table 2. Distribution of gross revenue(winter fishery 1971-73 inclusive).

Income interval ($)	Winter 1973	Winter 1972	Winter 1971
000- 499	14	20	40
500- 999	7	16	12
1000-1499	6	2	3
1500-1999	3	2	1
2000-2499	4	1	1
2500-2999	0	0	0
3000-3499	3	0	0
3500-3999	0	0	0
4000-4499	0	1	0
4500-4999	0	0	0
5000-5499	0	0	0
5500-5999	0	1	0
Number individuals selling fish to FFMC	37	43	57

Source: Economics Branch records of fish sales to the FFMC.

Table 3. Average number of deliveries by income interval(winter 1973).

Income interval ($)	Number deliveries	Number individuals	Average number of deliveries
0- 499	116	14	8.3
500- 999	146	7	20.9
1000-1499	138	6	23.0
1500-1999	78	3	26.0
2000-2499	117	4	29.2
2500-2999	0	0	0
3000-3499	106	3	35.3
Total fishery	701	37	18.9

Source: Economics Branch records of fish sales to the FFMC.

miscellaneous variable costs. The latter included such items as mit boots, sideline, etc. Also included as miscellaneous variable costs small items of equipment, such as ice chisels, purchased during the winter fishery. Fixed costs included depreciation and interest char for fishing gear, toboggans, and dog harnesses. An arbitrary deprec and interest charge was also set aside for the fish camp used by ent A while no similar charge was included for enterprise B since they u lodging provided by the cooperative at no charge.

Since enterprise A fished a greater number of nets and the av catch per net per night was greater, total production was greater. the estimated unit cost of production of 5.89¢/lb was 0.84¢/lb lower the estimated 6.73¢/lb cost of production for enterprise B.

2.5 Revenue - Expenditure analysis (bombardiers):

The remaining 7 of the 11 fishermen who participated in the s grouped into 4 bombardier enterprises. The revenue-expenditure anal for these enterprises is outlined in Table 6 and Table 7.

A comparison of the enterprises shows a considerable range in revenues, expenditures, and net earnings. In particular, variable c differ because of the differences in labor employed; since charges f provisions are calculated only for labor employed and not for "owner operators", the differences become even greater. Enterprise A emplo 2 men for 3 days each at a daily wage rate of $15 per day; enterpri employed 2 men at $300 basic wage for the season plus provisions; enterprise C employed one man at $300 per month plus provisions; fin

Table 4. Revenues and expenditures (dog teams).

Item	Enterprise A	Enterprise B
	($)	($)
Revenues		
fish sales	2256	1452
miscellaneous	-	-
Total revenue	2256	1452
Costs		
Variable costs		
freight	256	158
labor	-	-
maintenance	-	-
fuel & lubrication	-	-
provisions	-	-
miscellaneous	182	155
Subtotal variable	438	313

Table 5. Revenue - Expenditure analysis summarized (dog teams).

Item	Enterprise A		Enterprise B	
	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)
Revenue	2256	16.77	1452	16.55
Variable costs	438	3.26	313	3.57
Fixed costs	354	2.63	277	3.16
Total costs	792	5.89	590	6.73
Operating profit	1818	13.51	1139	12.98
Net earnings	1464	10.88	862	9.82
Net earnings per individual	732	5.44	431	4.91
Net earnings per individual per day[1]	32		16	
Breakeven point	2620 lb		2134 lb	

[1] This is the estimate of the daily wage to the "owner-operator".

Table 6. Revenues and expenditures (bombardiers).

Item	Enterprise A	Enterprise B	Enterprise C	Enterprise D
	($)	($)	($)	($)
Revenues				
fish sales	4117	4171	3193	6674
miscellaneous	-	-	-	-
Total revenue	4117	4171	3193	6674
Costs				
Variable costs				
freight	-	-	-	-
labor	90	600	600	300
maintenance	329	262	940	860
fuel & lubrication	141	281	289	342
provisions	20	480	160	100
miscellaneous	282	278	182	160
Subtotal variable	862	1901	2171	1762
Fixed costs				
depreciation	509	616	141	580
interest	187	202	60	135
miscellaneous	49	74	33	68
Subtotal fixed	745	892	234	783
Total costs	1607	2793	2405	2545
Net earnings enterprise	2510	1378	788	4129

Table 7. Revenue - Expenditure analysis summarized (bombardiers).

Item	Enterprise A Total ($)	Enterprise A Average (¢/lb)	Enterprise B Total ($)	Enterprise B Average (¢/lb)	Enterprise C Total ($)	Enterprise C Average (¢/lb)	Enterprise D Total ($)	Enterprise D Average (¢/lb)
Revenue	4,117	16.95	4,171	15.45	3,193	14.62	6,674	17.82
Variable costs	862	3.55	1,901	7.04	2,171	9.94	1,762	4.71
Fixed costs	745	3.07	892	3.30	234	1.07	783	2.09
Total costs	1,607	6.62	2,793	10.34	2,405	11.01	2,545	6.80
Operating profit	3,255	13.40	2,270	8.41	1,022	4.68	4,912	13.11
Net earnings	2,510	10.33	1,378	5.11	788	3.61	4,129	11.03
Net earnings per individual	1,255	5.17	689	2.55	788	3.61	2,065	5.52
Net earnings per individual per day[1]	41		21.50		33		47	
Breakeven point	5560 lb		10,606 lb		5,641 lb		5,972 lb	

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[1] This is the estimate of the daily wage to the "owner-operator".

enterprise D employed one man for one month at a wage rate of $300 per month. Enterprise C had the largest total variable cost, because of the charges for maintenance and repair. The high charges for maintenance and repair for this enterprise are paralleled by considerably lower total fixed costs, since the bombardier was treated as being fully depreciated.

2.6 Summary - winter fishery:

The distribution of gross income for the winter fishery suggests that generally a low level of capital and labor are employed in the winter fishery. The short duration of participation in the winter fishery made it very difficult to interview fishermen. Consequently, the winter survey was restricted in size and involved only those fishermen who actively participated in the fishery.

The revenue-expenditure analysis for the fishermen interviewed showed considerable diversity in the types of operations. The unit cost of production, the daily wage rate, and the breakeven point are three calculations which illustrate these differences. For dog team enterprises the daily wage rate for "owner-operators" ranged from $16-$32 per man per day. The calculated breakeven points show that before a net return to labor for the "owner-operators" accrued, it was necessary to produce from 2,134 lb to 2,620 lb of fish. The unit cost of production ranged from 5.89¢/lb to 6.73¢/lb.

For bombardier enterprises, the daily wage rate ranged from $21.50-$47 per man per day. The breakeven points ranged from 5,560 lb to 9,540 lb although for 3 of the enterprises the breakeven point was in the 5,500-6,000 lb range. Unit costs of production ranged from 6.62¢/lb - 11.01¢/lb.

CHAPTER 3

SUMMERY FISHERY

3.1 Description of summer fishery:

The catch statistics for the years Southern Indian Lake has been summer fished are summarized in Figure 22 and 23 and Table 8 of the main report. As with the winter fishery, whitefish is the major commercial specie and on the average has comprised 86% of the total landings. Statistics for the recent years of the fishery, derived from the FFMC weighbill, are summarized in Table 8.

3.2 Operation of summer fishery:

The gear type and yardage restrictions, as for the winter fishery, restrict fishing operations to the use of 1,500 yd gillnet per license. The pattern of production is such that the duration of the set is one night on the average. As opposed to the winter fishery where nets are not moved often, there is a tendency to move nets once catch/effort drops considerably. Also, over the course of the summer fishermen move from camp to camp on the lake. Transportation modes used are more standard than in the winter fishery, with fishermen using skiffs or yawls (on the average 20' or less in length) powered by one or two outboard motors.

The agency operation provided by the cooperative is in many ways similar to the winter fishery. As well as the Loon Narrows station, the cooperative packs fish at camp 3 and camp 9. Transportation of fish from

Table 8. Landings, landed value, average price (summer fishery 1971-1973 inclusive).

Season	Summer 1973	Summer 1972	Summer 1971
Weight (round equivalent)	740,398 lb	490,996 lb	746,731 lb
Landed value	$84,937	$72,517	$101,998
Average price	11.47¢/lb	14.76¢/lb	13.66¢/lb

Source: Economics Branch records of fish sales to the FFMC. There exists a considerable discrepancy between Province of Manitoba records and the records listed above for the summer 1972 season. Given the administrative difficulties the FFMC encountered at that time, the landed weight (unconverted) of 712,900 lb and landed value of $149,807 reported by the Province seem more reliable.

Table 9. Distribution of gross revenue (summer fishery 1973, 1971, 1970).

Income interval	Summer 1973	Summer 1971	Summer 1970
($)			
000- 499	10	18	26
500- 999	14	16	28
1000-1499	16	16	13
1500-1999	4	12	10
2000-2499	5	6	4
2500-2999	5	1	0
3000-3499	5	2	0
3500-3999	4	0	1
4000-4499	1	1	0
4500-4999	0	0	0
5000-5499	0	0	1
5500-5999	1	3	0
Number individuals selling fish to FFMC	65	75	83

Source: Economics Branch records of fish sales to the FFMC.

Table 10. Average number of deliveries by income interval (summer 1973).

Income interval ($)	Number deliveries	Number individuals	Average number of deliveries
000- 499	59	10	5.9
500- 999	320	14	22.9
1000-1499	560	16	35.0
1500-1999	176	4	44.0
2000-2499	279	5	55.8
2500-2999	244	5	48.8
3000-3499	311	5	62.2
3500-3999	213	4	53.2
4000-4499	73	1	73
4500-4999	0	0	0
5000-5499	0	0	0
5500-5999	77	1	77
Total fishery	2,312	65	35.6

Source: Economics Branch records of fish sales to the FFMC.

camps to Leaf Rapids is provided by the cooperative using a fish freighter (transport rate 1.5¢/lb). Once delivered to Leaf Rapids, the fish is re-iced, re-packed, and stored for shipment to Lynn Lake. From Lynn Lake the fish is shipped by rail to the FFMC plant in Transcona.

3.3 Analysis of gross earnings:

The distribution of gross income amongst fishermen for the summer seasons 1973, 1971, and 1970 is summarized in Table 9. For the 1973 summer fishery, 62% of the fishermen who sold fish to the FFMC earned less than $1,500. This compared with 67% who earned less than $1,500 in the 1971 summer fishery and 81% who earned less than $1,500 in the 1970 summer fishery.

The breakdown of average number of deliveries by income interval shows the direct relationship between effort (measured in deliveries) and gross revenue. This is summarized in Table 10.

3.4 Revenue-Expenditure analysis:

The diversity of fishing operations found in the winter fishery exists in the summer fishery as well. Here, however, primary differences lie not in the transportation modes used but in the number of individuals within the enterprise. Of the 28 fishermen who participated in the survey, 18 enterprises were defined; 6 fishermen fished alone with no additional labor employed (labelled enterprises A-F inclusive); 2 fishermen employed additional labor (labelled enterprises G and H); 18 of the fishermen fished in pairs with no additional labor employed (labelled enterprises I-Q inclusive); finally, one pair of fishermen employed additional labor (labelled enterprise R). The analysis of revenues and expenditures for these enterprises is detailed in Tables 11 and 12.

3.5 Summary (summer fishery):

The diversity in summer fishing operations is borne out by the revenue-expenditure analysis. Similar to the summary for the winter fishery, the unit cost of production, the daily wage rate, and the brea even point are three calculations which serve to illustrate these differences.

For the 6 fishermen fishing alone, the daily wage averaged $24 p man per day (range $10-$56). The average level of production at which net return to labour for the "owner-operator" accrued was 5,263 lb (ran 2,684 lb-6,982 lb). Unit costs of production for these enterprises averaged 6.82¢/lb (range 4.83¢/lb-10.22¢/lb).

For the fishermen employing additional labor, the daily wage rat were $24 per man per day and $26 per man per day. Breakeven points wer 9,477 lb and 10,093 lb respectively. Also, the unit costs of productio were 6.62¢/lb and 9.26¢/lb.

For the fishermen fishing in pairs, the daily wage rate was approximately $21.50 per man per day (range $12-$33). The average leve of production at which a net return to labor for the "owner-operators" accrued was 6,016 lb (range 4,460-7,352 lb). Unit costs of production for these enterprises averaged 4.18¢/lb (range 3.35¢/lb-5.99¢/lb).

For the pair of fishermen employing additional labor, the daily rate was $15 per man per day. The breakeven point was 13,442 lb and th unit cost of production 7.97¢/lb.

Table 11. Revenues and expenditures (summer fishery).

Item	Enterprise A ($)	Enterprise B ($)	Enterprise C ($)	Enterprise D ($)
Revenues				
fish sales	1217	1328	3074	1373
miscellaneous	-	-	-	-
Total revenue	1217	1328	3074	1373
Costs				
Variable costs				
labor	-	-	-	-
maintenance	-	100	-	75
fuel & lubrication	292	147	442	206
provisions	-	-	-	-
miscellaneous	-	27	32	25
Subtotal variable	292	274	474	306
Fixed costs				
depreciation	221	466	509	393
interest	36	105	114	87
miscellaneous	20	19	31	23
Subtotal fixed	277	590	654	503
Total costs	569	864	1128	809
Net earnings enterprise	648	464	1946	564

Table 11 cont.

Item	Enterprise E ($)	Enterprise F ($)	Enterprise G ($)	Enterprise H ($)
Revenues				
fish sales	2810	1333	4004	5706
miscellaneous	-	-	-	-
Total revenue	2810	1333	4004	5706
Costs				
Variable costs				
labor	-	-	425	1425
maintenance	60	-	100	50
fuel & lubrication	225	157	383	735
provisions	-	-	340	380
miscellaneous	68	28	105	219
Subtotal variable	353	185	1353	2809
Fixed costs				
depreciation	622	466	572	600
interest	126	108	156	130
miscellaneous	19	20	51	45
Subtotal fixed	767	594	779	775

Table 11 cont.

Item	Enterprise I ($)	Enterprise J ($)	Enterprise K ($)	Enterprise L ($)
Revenues				
fish sales	2653	3318	1558	1838
miscellaneous	-	-	-	-
Total revenue	2653	3318	1558	1838
Costs				
Variable costs				
labor	-	-	-	-
maintenance	50	-	-	-
fuel & lubrication	202	480	225	292
provisions	-	-	-	-
miscellaneous	132	39	62	50
Subtotal variable	384	519	287	342
Fixed costs				
depreciation	524	352	388	431
interest	125	60	89	171
miscellaneous	42	46	16	17
Subtotal fixed	691	458	493	619
Total costs	1075	977	780	961
Net earnings enterprise	1578	2341	778	877

Table 11 cont.

Item	Enterprise M ($)	Enterprise N ($)	Enterprise O ($)	Enterprise P ($)
Revenues				
fish sales	6750	3903	3576	5222
miscellaneous	-	-	-	-
Total revenue	6750	3903	3576	5222
Costs				
Variable costs				
labor	-	-	-	-
maintenance	-	20	-	-
fuel & lubrication	735	300	255	262
provisions	-	-	-	-
miscellaneous	-	18	74	108
Subtotal variable	735	338	329	370
Fixed costs				
depreciation	653	548	595	623
interest	151	120	128	138
miscellaneous	68	23	49	57
Subtotal fixed	872	691	772	818

Table 11 cont.

Item	Enterprise Q	Enterprise R
	($)	($)
Revenues		
fish sales	2211	4803
miscellaneous	-	-
Total revenue	2211	4803
Costs		
Variable costs		
labor	-	1020
maintenance	-	-
fuel & lubrication	360	735
provisions	-	280
miscellaneous	25	84
Subtotal variable	385	2119
Fixed costs		
depreciation	470	714
interest	73	156
miscellaneous	41	71
Subtotal fixed	584	941
Total costs	969	3060
Net earnings enterprise	1242	1743

Table 12. Revenue-expenditure analysis summarized (summer fishery)

Item	Enterprise A		Enterprise B		Enterprise C		Enterprise D	
	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)
Revenue	1217	13.58	1328	10.64	3074	13.16	1373	10.56
Variable costs	292	3.26	274	2.19	474	2.03	306	2.35
Fixed costs	277	3.09	590	4.72	654	2.80	503	3.87
Total costs	569	6.35	864	6.91	1128	4.83	809	6.22
Operating profit	925	10.32	1054	8.45	2600	11.13	1067	8.21
Net earnings	648	7.23	464	3.73	1946	8.33	564	4.34
Net earnings per individual	648	7.23	464	3.73	1946	8.33	564	4.34
Net earnings per individual per day[1]	15		14		31		10	
Breakeven point	2684 lb		6982 lb		5876 lb		6127 lb	

[1] This is the estimate of the daily wage to the "owner-operator".

Table 12 cont.

Item	Enterprise E		Enterprise F		Enterprise G		Enterprise H	
	Total ($)	Average (¢/1b)	Total ($)	Average (¢/1b)	Total ($)	Average (¢/1b)	Total ($)	Average (¢/1b)
Revenue	2810	25.63	1333	10.87	4004	12.42	5706	14.74
Variable costs	353	3.22	185	1.51	1353	4.20	2809	7.26
Fixed costs	767	7.00	594	4.85	779	2.42	775	2.00
Total costs	1120	10.22	779	6.36	2132	6.62	3584	9.26
Operating profit	2457	22.41	1148	9.36	2651	8.22	2897	7.48
Net earnings	1690	15.41	554	4.51	1872	5.80	2122	5.48
Net earnings per individual	1690	15.41	554	4.51	1872	5.80	2122	5.58
Net earnings per individual per day [1]	56		16		24		26	
Breakeven point	3423 1b		6346 1b		9477 1b		10093 1b	

1. This is the estimate of the daily wage to the "owner-operator".

Table 12 cont.

Item	Enterprise I		Enterprise J		Enterprise K		Enterprise L	
	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)
Revenue	2653	12.87	3318	12.17	1558	9.80	1838	11.45
Variable costs	384	1.86	519	1.90	287	1.81	342	2.13
Fixed costs	691	3.35	458	1.68	493	3.10	619	3.86
Total costs	1075	5.21	977	3.58	780	4.91	961	5.99
Operating profit	2269	11.01	2799	10.27	1271	7.99	1496	9.32
Net earnings	1578	7.66	2341	8.59	778	4.89	877	5.46
Net earnings per individual	789	3.83	1170	4.29	389	2.45	438	2.73
Net earnings per individual per day[1]	19		22		12		12	
Breakeven point	6276 lb		4460 lb		6170 lb		6642 lb	

[1] This is the estimate of the daily wage to the "owner-operator".

Table 12 cont.

Item	Enterprise M		Enterprise N		Enterprise O		Enterprise P	
	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)
Revenue	6750	13.31	3903	14.37	3576	14.48	5222	14.75
Variable costs	735	1.45	338	1.25	329	1.33	370	1.05
Fixed costs	872	1.72	691	2.54	772	3.13	818	2.31
Total costs	1607	3.17	1029	3.79	1101	4.46	1188	3.36
Operating profit	6015	11.86	3565	13.12	3247	13.15	4852	13.70
Net earnings	5143	10.14	2874	10.58	2475	10.02	4034	11.39
Net earnings per individual	2572	5.07	1437	5.29	1237	5.01	2017	5.70
Net earnings per individual per day[1]	32		31		20		33	
Breakeven point	7352 lb		5263 lb		5871 lb		5971 lb	

---

[1] This is the estimate of the daily wage to the "owner-operator".

Table 12 cont.

Item	Enterprise Q		Enterprise R	
	Total ($)	Average (¢/lb)	Total ($)	Average (¢/lb)
Revenue	2211	11.51	4803	12.52
Variable costs	385	2.00	2119	5.52
Fixed costs	584	3.04	941	2.45
Total costs	969	5.04	3060	7.97
Operating profit	1826	9.51	2684	7.00
Net earnings	1242	6.47	1743	4.55
Net earnings per individual	621	3.23	872	2.27
Net earnings per individual per day[1]	13		15	
Breakeven point	6141 lb		13442 lb	

1. This is the estimate of the daily wage to the "owner-operator".

CHAPTER 4

SUMMARY

Sections 2.6 and 3.5 summarize the information collected during the winter 1973 and summer 1973 commercial fisheries on Southern Indian Lake. These surveys have provided economic information on northern fishing operations previously not available elsewhere.

One of the major obstacles in doing these surveys was the fact that few fishermen maintained records of revenues and expenses. While this made the survey difficult and leads one to question the quality of the data presented in this report, the greater concern is the need to introduce basic business principles to the primary producer. It is the opinion of the author that, in the array of government programs available to mitigate effects of the hydro development, an on-site training program for fishermen could be readily justified.

Appendix VIII

CHURCHILL-NELSON STUDY: INDIVIDUAL ANGLING RECORD

BACKGROUND:

The purpose of this survey is to obtain comparative data on the quality of angling in different lakes, and in different parts of Southern Indian Lake.

INSTRUCTIONS:

1. Record information for each time you do any fishing, regardless of whether you catch any fish.
2. Do not include anyone else's fishing statistics on your form, even if he fished in the same boat. This is an individual record.
3. Complete a new form each time you fish. If you fish twice in one day, use two forms. Also start a new form if you change angling type or lure type. Avoid such changes.
4. Measure all fish caught (fork lengths). Record units (inches or cm).
5. Record times to nearest quarter hour.

Name of Lake: ________________ Date: ________________

Name of Angler: ________________

Exact location, latitude: ____________ longitude: ________________

Nature of site (check applicable items):

( ) mainland
( ) bedrock
( ) marsh
( ) island
( ) boulders
other
( ) gravel, sand

Type of angling (check):

( ) trolling
( ) boat-casting
( ) shore-casting

Type of lure (check):

( ) spoon
( ) plug
( ) fly

Weather (check):

( ) calm
( ) sunny
( ) choppy
( ) cloudy
( ) whitecaps
( ) rain

Time: start: ____________ finish: ____________ hours: ________

Appendix VIII (cont'd)

Measurements of fish caught: ( ) inches ( ) centimeters

Pike	Walleye	Sauger	Trout		

LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

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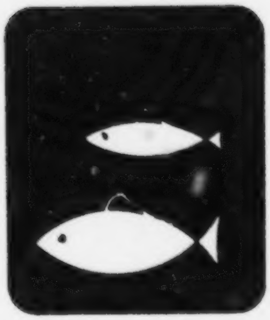

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fisheries and limnology vol.2

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APPENDIX 5 - FISHERIES AND LIMNOLOGY STUDIES, VOL. 2

A - THE LIMNOLOGY-FISHERIES OF THE OUTLET LAKES AREA: PRESENT CONDITIONS AND IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

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D - THE MORPHOMETRY OF RAT-BURNTWOOD DIVERSION ROUTE AND LOWER CHURCHILL RIVER LAKES: PRESENT CONDITIONS AND POST REGULATION CONDITIONS

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THE LIMNOLOGY-FISHERIES
OF THE OUTLET LAKES AREA
PRESENT CONDITIONS AND
IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

by

G. D. KOSHINSKY
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
March, 1973

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

Environment Canada | Environnement Canada
Fisheries | Pêches

March 15, 1973
Your file Votre référence

Our file Notre référence

Dr. Ian Dickson, Study Director
Lake Winnipeg, Churchill and Nelson Rivers Study
693 Taylor Avenue
Winnipeg, Manitoba
R3M 2K2

Dear Dr. Dickson:

I submit herewith 15 copies of a report entitled "The limnology-fisheries of the Lake Winnipeg Outlet Lakes area: Present conditions, and the implications of hydro-electric development".

This report is in partial fulfillment of the contract agreement between Canada and the Province of Manitoba (23 August 1972) for fisheries-limnology studies to be undertaken by the Freshwater Institute, Environment Canada, under the Lake Winnipeg, Churchill and Nelson Rivers Study Agreement. The report deals explicitly with that geographical component of the Study Area designated as "Outlet Lakes". An appropriate short title for the report would be "Limnology-fisheries of the Outlet Lakes".

Most of the findings and conclusions presented are considered to be of a preliminary nature, and the option is reserved to make such changes and additions as may be appropriate if and when further information, specifications, implications, and assessments become available under the terms of the Agreement. The evaluations of the impacts of hydro-electric development and the recommendations are generally tentative and, of course, rather parochial. It will be noted that, although certain base-line economic data are presented, evaluation of impacts has generally been taken only to the biological level. Our immediate concern was to assemble and interpret the existing resource data base, and to establish some directions along which subsequent evaluations might proceed. Participation in a more comprehensive evaluation of these issues with other study sectors under the auspices of the Study Office is anticipated for the immediate future.

Yours very truly

Gordon D. Koshinsky

Gordon D. Koshinsky
Program Leader, Basin Studies
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GDK/nm
Enclosure

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CONTRIBUTING AUTHORS

This document is based on a number of earlier reports, working papers, and assorted communications. Some of the background reports were prepared directly or indirectly for the Lake Winnipeg, Churchill and Nelson Rivers Study; others were done independently. They include:

1) Ayles, H. A. MS 1973. The limnology-fisheries of Playgreen and Kiskittogisu Lakes, Manitoba. Part II. Morphometry, biology, and fisheries. Manitoba Hydro MS Rep. (In preparation).

* 2) Driver, E. A. and K. H. Doan. MS 1972. Fisheries survey of Cross Lake (Nelson River), 1965. Manitoba Dept. Mines, Res., and Env. Mgmt., Research Branch. MS Rep. 73-5: 17 p.

* 3) Pollard, W. R. MS 1973. A preliminary evaluation of whitefish movements in the north basin of Lake Winnipeg and between Lake Winnipeg and Playgreen Lake. Manitoba Dept. Mines, Res., and Env. Mgmt. MS Rep. 17 p. + appendix.

* 4) Schlick, R. O. MS 1972. A fisheries survey of Playgreen Lake, 1971. Manitoba Dept. Mines, Res., and Env. Mgmt. MS Rep. 18 p. + maps.

* 5) Schlick, R. O. MS 1973. A fisheries survey of Kiskittogisu and Kiskitto Lakes, 1972. Manitoba Dept. Mines, Res., and Env. Mgmt. MS Rep. (In preparation).

6) Stockner, J. G. MS 1973. The limnology of Playgreen and Kiskittogisu Lakes, Manitoba. Part I. Physical and chemical features. Manitoba Hydro MS Rep. 18 p. + appendix.

7) Weagle, K. V. MS 1973. Fisheries of the Lake Winnipeg Outlet Lakes: exploitation and reproduction. Environment Canada Fisheries Service MS Rep. (In preparation).

* Reports marked by asterisks are cited throughout the text as personal communications from the particular author(s).

ABSTRACT

Lakes on the Upper Nelson River system just below Lake Winnipeg central Manitoba are generally quite productive. These lakes are war and richer in nutrients and dissolved ions than lakes of the Churchil River system located in the same general area. The most productive l are those that exchange directly with the Nelson River, but which are large enough to dampen the negative effects of flushing.

These waters are very turbid, reflecting the quality of input fr Lake Winnipeg, and more specifically the glacio-lacustrine shore and bottom deposits. Primary production is probably not the main basis f the generally high fish and bottom fauna values; greater importance i attached to the drift of plankton algae, detritus, and other material via the massive Nelson River discharge.

The fish fauna is diverse and complicated in its ecology. The d ferent waters appear to harbor mainly discrete fish populations. How there is an important seasonal interchange of whitefish between Lake Winnipeg and Playgreen Lake, and perhaps a more general movement of f in and out of Kiskitto Lake.

The Outlet Lakes contribute 5% of current Manitoba commercial fi landings, and 8% of values. There are two significant domestic fishe but no sport fishery. Whitefish and walleye contribute the bulk of t commercial gillnet harvest, with about 60% of the Outlet Lakes fisher occurring on Playgreen Lake. The economics of exploitation are stron influenced by access.

Little overall impact on fish productive potentials is anticipat from the proposed hydro-electric developments and operations in the C Lakes area. Some decline in productivity is forecast for Playgreen L but this will be compensated by increased productivity in Kiskittogis Kiskitto Lakes. Development will create significant new fishing envi ment in the Jenpeg forebay and tailwater areas; new access will expar fishing opportunities throughout most of the region. The 8-mile char will destroy significant fish reproductive habitat in Kiskittogisu Ri Jenpeg operation will interfere with mobility of fishermen on Cross L Inundation of shorelines will disbenefit fish exploitation in the Jer forebay, and in Kiskittogisu Lake.

Mitigation opportunities include possible control on the Cross L outlet, measures to more rapidly stabilize new shorelines on Kiskitto Lake, a revamped clearing program for the Jenpeg forebay, guaranteed minimum flows in the East Channel(s), and provision of fish passage f ities (or demonstration of the need for such facilities) in river con and crossing structures.

A monitoring program for offshore sedimentation effects in Kiski and Playgreen Lakes is recommended. There is also a need for more de field assessments of whitefish interchange between Playgreen Lake and Winnipeg, and for limnology-fisheries studies on Cross Lake.

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1. SUMMARY

a) The existing data on limnology-fisheries in the Lake
Outlet Lakes area are summarized and integrated. Eig
along with the connecting Nelson River sections are i
most of the basic data are from Playgreen, Kiskittogi
and Cross Lakes. Issues confronting the fisheries fr
electric development and operation are briefly define
mendations presented.

b) The lakes are situated on the Canadian Shield, but gl
clays and silts predominate in the surficial deposits
These exert a marked edaphic effect on the waters.

c) The lakes range in water area from 4.2 square miles (
250 square miles (Playgreen), and occupy a combined a
740 square miles.

d) From 36-70% of the individual lake areas are less tha
at ordinary supply levels. Significant departures to
are confined to corridors of active water movement.

e) Shorelines are somewhat more regular than is typical
Lakes, except for Cross Lake. The shoreline of Cross
dominantly bedrock-controlled, and is extremely irreg

f) Renewal times range from about 2 days in interconnect
sections between major lake basins, to 2 years or mor
locations such as Kiskitto Lake.

g) The lakes remain nearly isothermal during the ice-fre
Surface temperatures do not exceed 20°C. The Nelson

exerts a warming influence in summer and autumn, and retards autumn cooling. This reflects the greater warming and massive heat inertia of Lake Winnipeg to the south.

h) Dissolved oxygen remains saturated or near-saturated at all depths in all lakes in summer. Significant depletion occurs under the ice only at inshore stations in isolated bays removed from the main channel of the Nelson River. This situation is clearly promoted by river flow; however a low rate of primary production may be the major contributing factor.

i) Water in the Outlet Lakes is less transparent than in Lake Winnipeg, indicating uptake of suspended matter by wind and current action from the glacio-lacustrine shore and bottom deposits. Greater turbidity in Kiskittogisu than in Playgreen is evident only during elevated wind conditions, thus demonstrating the role of the Nelson River in clearing the lakes. Kiskitto Lake is the most turbid of the lakes examined, and is also the most isolated from the Nelson River. The east basin of Cross Lake is less turbid than that section receiving Nelson River discharge. Turbidities of the nature encountered in the Outlet Lakes would have a marked negative impact on biological productivity.

j) Total dissolved solids of about 230 parts per million and pH of 7.5-8.0 reflect the characteristics of the Lake Winnipeg discharge. Major ions tend to increase in concentration through Playgreen and Kiskittogisu, but exhibit some dilution in the other lakes. Nutrient ions and complexes along with heavy metals (notably mercury and zinc) appear to be retained in passage through these lakes. Nutrient loading values are very high, due to the massive water discharge.

k) Amphipods (particularly Pontoporeia affinis), sphaeriids (particularly Sphaerium sp.), and large burrowing mayfly nymphs (Hexagenia sp. and Ephemera sp.) generally dominate the zoobenthos of these lakes. Notable is the scarcity of dipteran larvae. Mayflies probably make a predominant contribution to fish feeding ecology. Of these the more important is Hexagenia, which is more abundant where the discharge of the Nelson River is less apparent.

l) Overall bottom fauna standing crop is greatest in those areas which receive the full discharge of the Nelson River, but which are large enough to dampen the flushing impact (i.e. south and north basins of Playgreen Lake). Standing crops are lowest in the most isolated basins (i.e. Kiskitto Lake and the main part of Kiskittogisu Lake).

m) At least 21 fish species occur in these lakes, including lake whitefish, cisco, walleye, sauger, northern pike, perch, goldeye, sturgeon, and suckers. Playgreen Lake appears to have the greatest overall fish standing crop; Kiskittogisu and Cross Lakes have about half as much, and Kiskitto about half as much again. Playgreen is probably somewhat more productive of fish than the best Churchill-River lakes; with the other Outlet Lakes ranked in the approximate order of their standing crops.

n) Whitefish generally decrease in abundance, growth, size, and condition from the south basin of Playgreen Lake downstream and into the main basin of Kiskittogisu Lake. Growth appears to increase again in Cross Lake. Pike are larger, plumper, and more abundant in Playgreen Lake (especially the extreme south end) than in Kiskittogisu, but are slightly larger at specific ages in the latter. Walleye productivity seems to be linked to the availability of tributary streams, such as Kiskittogisu River, Minago River, and Black Duck Creek, which are probably utilized for reproduction. Walleye growth is slightly faster in Kiskittogisu Lake than elsewhere in these waters. Goideye are encountered only in the lower of these lakes (below Kiskittogisu). Sturgeon are presently known only from Playgreen and Cross Lakes.

o) Indications are that discrete populations of the economic fish species inhabit the main individual lakes, and that the commercial fisheries are based on indigenous stocks. The possibility of extensive fish exchange between Kiskitto and Kiskittogisu Lakes is not disproved, however, and there are no data to assess such interchange for Cross-Pipestone-Drunken-Walker. Similarly, there are no data on fish migrations up and down the main channels of the Nelson River below Playgreen Lake, but it seems unlikely that this would be extensive.

p) Whitefish tagged in Lake Winnipeg were recovered in Little Playgreen Lake, and it is probable that this is part of an important spawning phenomenon with major implications for the Lake Winnipeg whitefish fishery as well as for domestic fishing in Little Playgreen Lake.

q) There is no concerted sport-fishery in the area. There are, however, some locally attractive stocks of walleye (particularly in Drunken Lake) and northern pike (particularly in South Playgreen Lake and in the Nelson River channels).

r) Substantial domestic gillnet fisheries are conducted on Cross and Little Playgreen Lakes. Estimates vary greatly, from about 75,000 to 300,000 lb annually for Cross Lake, and from about 100,000 to 400,000 lb annually for Little Playgreen. Whitefish are believed to be the main component of the domestic utilization, at least in Little Playgreen. It is doubtful that Little Playgreen Lake could support a domestic removal of the magnitude indicated, by whatever estimate (4.4-17.2 lb/acre), without migration of fish into the area.

s) The lakes in question are currently gazetted for 560,000 lb total commercial fish production annually. The combined harvest over the past 12 years has averaged 522,000 lb. The Outlet Lakes provide about 5% of the Manitoba landings, and 8% of the values. Playgreen Lake is the main contributor to landings (59%), values (58%), and participation (65%).

t) Mean annual production has ranged from 0.29 lb/acre (Kiskitto Lake) to 3.43 lb/acre (Drunken Lake). Whitefish have been the main contributors to the marketed catch from Playgreen, Pipestone, Cross, and Walker Lakes; walleyes are the main contributors from Kiskittogisu, Kiskitto, and Drunken Lakes. The Playgreen fishery appears unrelated, in volume and in composition trends, to that of Lake Winnipeg.

u) Ultimate production potentials probably exceed current commercial harvest rates by about 2-10 times. However recent annual production is probably the most reasonable basis, in most cases, for estimating present and future values.

v) Fish taken in the Playgreen Lake commercial fishery are moved by boat to the secondary receiving station in Winnipeg, at a cost of 4.75¢ per lb. Fish from the other lakes are flown to Wabowden (some are taken by bombardier in winter) at a cost of 4.1 to 6.3¢ per lb depending on distance. Shipment from Wabowden to The Pas and on to Winnipeg costs another 3.05-3.75¢/lb, depending on choice of carrier. In addition, agents operating for the Freshwater Fish Marketing Corporation in the purchase and transport of the fish from the fishermen are allowed about 9¢ per lb to cover administration, packing and other labor, ice, and containers. These costs dictate to a considerable degree the economic feasibility of fishing particular species in particular lakes.

w) Capital and operating costs (other than packing and transport of fish) are estimated at about $1,500 annually for winter fishing, and $1,300 annually for summer fishing. Most operators earn less than $3,000 per season.

x) Numerous individual impacts on fish productivity in these waters will follow hydro-electric development. The major anticipated impacts are:

   i) Destruction of Kiskittogisu River and its associated lagoons and tributaries by the 8-mile channel excavation and by the accompanying dredge spoil deposition and shoreline inundation. This is expected to have a serious negative effect on reproduction of walleye, pike, and suckers.
   ii) Increased productivity of Kiskittogisu Lake because of increased water exchange induced by the 8-mile channel.
   iii) Decreased productivity of Playgreen Lake because of increased turbidity induced by the 2-mile channel.
   iv) Increased productivity of Kiskitto Lake because of higher and more stable water levels made possible by the Kiskitto Lake control works.
   v) Creation of significant new fishery habitat in the Jenpeg forebay and tailwater areas by the Jenpeg installation.
   vi) Possible interference by the 2-mile channel with whitefish exchange between Lake Winnipeg and Playgreen Lake.

The overall anticipated effect for the area as a whole is a slight decline in fish productive capacity over the short-term (due mainly to a slight expected drop in productivity in Playgreen Lake), and a slight increase thereafter (due mainly to expected increases in productivity in Kiskittogisu and Kiskitto Lakes).

y) There will be some important effects of hydro-electric development on fish exploitation opportunities. These relate mainly to access and include:

  - i) Improved boat access between Kiskittogisu Lake and Lake Winnipeg via the 8-mile channel.
  - ii) New permanent vehicle access to Kiskitto Lake, Cross Lake (west end), Minago River, and the Jenpeg forebay and tailwater areas, via the Jenpeg access road.
  - iii) In the event of East Channel control, new road access to Playgreen, Pipestone, and Cross Lakes, and also to the East Channel per se, and to the communities of Cross Lake and Norway House.
  - iv) Reduced mobility on Cross Lake, and from there to Walker and Drunken Lakes, due to lower summer and rising winter water levels.

It is noted that access opportunities and other socio-economic factors were not incorporated in the present evaluation program. The relevant economic data base is presented, but impacts and alternative opportunities appeared generally too limited to warrant a concerted economic evaluation of these effects at this time.

z) Although there are numerous apparent opportunities for alternative actions and mitigation measures to enhance fishery values, these are generally weak and difficult to support. The more significant feasible recommendations include:

  - i) Examine the feasibility of mitigating Cross Lake water levels by constructing outlet works, and by developing inflow forecasts for Lake Winnipeg.
  - ii) Revise clearing specifications and priorities for the Jenpeg forebay to accomplish total clearing at least in the downstream reaches.
  - iii) Re-assess the 8-mile channel dredging operation and the

accompanying shoreline inundation on Kiskittogisu Lake, with a possible view to stabilizing the new shorelines as quickly as feasible.

iv) Make provision for fish passage, or for assessing the need for such passage (to be installed if the need is demonstrated) in all artificial obstructions (Jenpeg control, East Channel control, Minago River crossing).

v) Provide minimum flows in the East Channel such that there is discharge in all channels at all times, with greater and more stable discharge during the spring spawning-incubation period.

vi) Provide at least 200 cfs constant inflow to Kiskitto Lake, and preferably more in winter. Regulate the lake between elevations 698 and 700 feet. Incorporate all feasible operating flexibility options in the inlet and outlet works.

vii) Conduct studies to better assess whitefish migrations between Lake Winnipeg and Playgreen Lake.

viii) Establish and operate sediment traps in Playgreen and Kiskittogisu Lakes to assess sedimentation effects of the 2-mile and 8-mile channels.

2. INTRODUCTION

This report undertakes to summarize and integrate the existing data on limnology-fisheries of the Lake Winnipeg Outlet Lakes, to evaluate this information in the light of impending or projected hy electric developments and operations, and to present such recommend as are considered appropriate from the data base available and with terms of reference.

The report is concerned primarily with four lakes (Playgreen, Kiskittogisu, Kiskitto, and Cross), and the connecting portions of Nelson River (Figure 1, at back of report). Four other lakes (Litt Playgreen, Pipestone, Walker, and Drunken) are also part of this ge phical study component; however they have received scant attention due to lack of information and/or relatively low or unpredictable a cipated impacts from hydro-electric development. It should be note virtually no specific limnology-fisheries field work was undertaken this geographical area under the terms of the Lake Winnipeg, Church and Nelson Rivers Study. However considerable data and records dic exist from earlier investigations, and this information forms the b of the present report. It was often very difficult to integrate th existing information, and to apply it to the particular objectives hand. Nevertheless these data were indispensible to the present ur taking because it was impossible to conduct on-site studies under e ing constraints.

This report has three major components. The existing status c limnology-fisheries and the historical fishery exploitation is firs documented, along with an attempt to define fishery potentials and critical factors in productivity. The major issues confronting these fisheries in terms of impending hydro-electric developments are then defined, and an attempt is made to evaluate and quantify their various impacts. Finally, recommendations are put forth as to design and/or operating specifications to minimize fishery disbenefits (or maximize benefits), to mitigate negative impacts, and to monitor future developments in the system.

3. DATA SOURCES AND GENERAL METHODOLOGY

The present report draws heavily for background material on t manuscripts and personal communications cited above under "Contrib authors". Stockner (MS 1973) has detailed the results of his inve gations of physical-chemical aspects of Playgreen and Kiskittogisu Lakes during the intervals 20 September to 20 October 1970, 21 Mar to 13 April 1971, and 17 July to 21 October 1971. For Stockner's gram, these two lakes were divided into five regions, designation which has been adopted for the present report as well. These regi are: South Playgreen Lake, Playgreen Lake channel, North Playgreen South Kiskittogisu Lake, and Kiskittogisu Lake channel. These reg along with the locations of actual sampling stations, are indicate the maps, Figures 2A, 2B and 2C at back of this report. Stockner' (MS 1973) data include temperature and dissolved oxygen profiles, Secchi disc readings, some chemical analyses, and a series of wint oxygen determinations.

Ayles (MS 1973) has analysed biological data and samples obt concurrently with the physical-chemical observations outlined by (loc. cit.) for Playgreen and Kiskittogisu Lakes. Bottom fauna (benthos) was analysed on the basis of 173 Ponar grab samples take key and transect stations (Figures 2A, B, C) in 1971. Fish were a from 97 "standard gang" gillnet sets made at "key" and "odd" stat 1971. (For details of gillnet specifications, see Table 1). Net set overnight, on the bottom, and with gangs in both "deep" and " water at each station.

Table 1. Specifications of gillnets used in experimental netting of Lake Winnipeg Outlet Lakes. All nets were of twined nylon and were set in gangs, overnight, on the lake bottom

Lakes sampled (investigating agency)	Year(s)	Source	Net characteristics				
			Mesh inches	Length yards	Depth meshes	Twine	Th
Playgreen	1971	R.O.Schlick,	3.0	50	24	210	
Kiskittogisu	1972	personal	3.75	50	24	210	
Kiskitto		comm.	4.25	50	16	210	
(Man. Dept.			4.75	50	16	210	
Mines, Res.,			5.25	50	16	210	
Env. Mgmt.)							
Playgreen	1970	Weagle,	1.5	50	60	210	
Kiskittogisu	1971	MS 1973	2.5	50	30	210	
			3.0	45	60	140	
(Manitoba			3.25	45	60	140	
Hydro)			3.75	45	40	140	
			4.25	45	40	210	
			5.0	45	40	210	
Cross	1965	K.H. Doan,	3.0	50	36	210	
		and	3.75	50	30	210	
(Man. Dept.		L. Sunde,	4.25	50	20	210	
Mines, Res.,		personal	4.75	50	18	210	
Env. Mgmt.)		comm.	5.25	50	16	210	

Schlick (personal communication) has provided limnology

data and preliminary analyses from brief cruises on Playgree

August 1971, on Kiskitto Lake in June 1972, and on Kiskittog

in July 1972. The Playgreen Lake survey included physical-c

observations at two stations, and 34 overnight sets of gilln

(Table 1). The Kiskittogisu and Kiskitto surveys incorporat

benthos sampling program and more extensive physical-chemica

along with the basic gillnetting. Data were obtained at 16

on Kiskittogisu Lake (area 5) and at 26 stations on Kiskitto

The stations visited by Schlick on these surveys of Playgree

Kiskittogisu, and Kiskitto Lakes are shown in Figure 1. In

Schlick also conducted an echo-sounding program for Kiskitto

his results are incorporated in the present report (Table 2;

at back).

Doan (personal communication) and Driver have made avai

results of a brief biological survey of Cross Lake, conducte

1965. This investigation included four overnight net sets (

nine Ekman grab samples for zoobenthos, depth soundings, com

fish sampling, and some physical-chemical observations. The

tour map presented here for Cross Lake (Figure 6, at back) w

of that study.

Contour maps of Playgreen and Kiskittogisu Lakes were d

Manitoba Hydro from their own echo sounding profiles. These

modified by Ayles (MS 1973) in the course of her morphometri

These maps have also been incorporated into the present repo

3 and 4, at back).

Pollard (personal communication) has conducted a prelim analysis and interpretation of whitefish interchange between Lake Winnipeg and Playgreen Lake. This analysis is based in part on a tagging program undertaken by the Manitoba Department Mines, Resou and Environmental Management in the autumns of 1970 and 1971.

The commercial fish catch statistics and economics data prese in this report, along with certain of the evaluations and recommen have been extracted and adapted from the synthesis of Weagle (MS 1 A variety of other data sources, both within and outside the Lake peg, Churchill and Nelson Rivers Study, have been employed. These cited in connection with the information where it is presented. S the chemical data were generated internally (Analytical Section, F water Institute); these are listed without further citation.

It might be noted that no physical-chemical or biological dat existed or were obtained for Little Playgreen, Pipestone, Walker, Drunken Lakes. Reference to these is made only incidentally in co nection with their present or prospective fisheries and/or antici impacts of Hydro developments.

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4. ACKNOWLEDGMENTS

This synthesis and evaluation has involved the specia
numerous individuals and organizations. I am indebted to
Department Mines, Resources and Environmental Management f
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Mrs. Ayles performed most of the statistical computations
cipated in all phases of the final report preparation.

5. THE GEOGRAPHIC BACKGROUND

The Outlet Lakes study area lies immediately north of Lake Winnipeg at the head of the Nelson River in central Manitoba. The climate is cold-continental, with a mean annual temperature of about 29°F, and a mean annual precipitation of 17 inches (one-third of which falls as snow).

The physiography of the area has been described by Beke et al. (MS 1973). According to these authors, the area "comprises portions of two physiographic provinces, namely the Manitoba Lowlands province of the Interior Plains . . . and the Superior province of the Canadian Shield. . . . . The Manitoba Lowlands portion . . . is underlain by Ordovician dolomite or dolomitic limestone . . . . The Superior portion . . . is underlain by granitic bedrock except for a small area of gneissic bedrock around the settlement of Cross Lake.". Virtually all of the area of concern in this study is in the Superior Province.

Most of the region was covered by Glacial Lake Agassiz during the last period of glacial recession. Surficial deposits, as a result, are predominantly lacustrine clays and silts. The meagre soil is mostly grey-wooded podzol, with heavy surface litter. Organic layers (peat, moss, fen) cover the surficial deposits over vast tracts, particularly in the southern portion of the area. However the lacustrine sediments in which the lake basins are situated exert the predominant local edaphic influence on the particular lakes.

The area is part of the Nelson River Section of the Boreal Forest Region of Canada as defined by Rowe (1972). Black spruce is the climax forest type, co-occurring with larch and white spruce in specific locales, and giving way temporarily to jackpine, aspen, and white birch following disturbance.

There are three permanent settlements in the Outlet Lakes area: Norway House (population 2,800), Cross Lake (population 1,930), and Warren Landing (population ±30). The population cited for Norway House includes that of the satellite community of Rossville (Study Office data compilation). In addition, there are substantial temporary Manitoba Hydro work camps in the area at the present time.

Access to the communities has been and remains by air or water in summer, and by air or winter road in winter. A secondary road was recently completed from Provincial Road 391 to the Jenpeg development site (Figure 1); however this provides service to Norway House and Cross Lake only during the winter months. Both communities have commercial air service and facilities, and Norway House is accessible by barge from Lake Winnipeg.

6. THE PRESENT STATE OF LIMNOLOGY-FISHERIES

6.1 Morphometry and water exchange:

Contour maps of Playgreen and Kiskittogisu Lakes are presented as Figures 3 and 4 inside the back cover of this report. Similar maps for Kiskitto and Cross Lakes are given as Figures 5 and 6, also at back of the report.

Playgreen and Cross Lakes are of similar size (250 and 205 square miles respectively). Kiskittogisu (97 square miles) and Kiskitto (86 square miles) are considerably smaller. Morphometric data for these and the other Outlet Lakes are summarized in Table 2. The combined water area of the eight Outlet Lakes (above Sipiwesk) is approximately 740 square miles.

These lakes are relatively very shallow, with vast littoral zones. From 36 to 70% of the areas of those that were sounded were less than 10 feet deep, and only the north channel region of Kiskittogisu Lake has significant area in excess of 20 feet. Of the four lakes sounded, Kiskittogisu is deepest overall (mean depth 14 feet; maximum depth 105 feet). This is attributed to the extensive river channel component (Figure 4) where the current presumably retards sedimentation. In any event, relatively great depths are consistently observed in association with river channels in lakes of the Churchill and Nelson Rivers in Manitoba and Saskatchewan. This effect is also very much evident in Playgreen and Cross Lakes, where the greatest depths are in the most constricted areas along water movement corridors (Figures 3 and 6). Kiskitto Lake, with no major river flowing through any portion of it,

Table 2. Summary of morphometric data for the Lake Winnipeg Outlet Lakes.

	Playgreen				Little	Kiskittogisu							
	South	Channel	North	Total	Playgreen	North	South	Total	Kiskitto	Pipestone	Cross	Drunken	Walker
Surface elevation[a], ft	714	713.5	713		712	711	711	711	700.6	682	681.3	679	679
Water area, '000 acres	78.6	22.3	59.0	159.9	23.8	10.3	51.5	61.8	55.2	11.2	131.2	2.7	28.2
Islands area, '000 acres	3.1	0.3	2.6	6.0	2.4	0.8	3.0	3.8	0.7	1.6	48.5	0.1	11.6
Outline area, '000 acres	81.7	22.6	61.6	165.9	26.2	11.1	54.5	65.6	55.9	12.8	179.7	2.8	39.8
Number of islands	138	12	104	254	71	47	64	111	185	35	714	34	208
% area <10 ft deep	53	49	61	46		36	36	36	60		70		
% area <20 ft deep	100	81	98	97		61	96	90	100		30		
Volume, thousand acre-feet	762	287	499	1548		240	607	847	390		936		
Mean depth, feet	9.7	12.9	8.5	9.7		23.2	11.8	13.7	7.1		7.1		
Maximum depth, feet	20	56	61	61		105	90	105	12		84		
Mean depth: max. depth	0.48	0.23	0.14	0.16		0.22	0.13	0.13	0.59		0.08		
Shorelength of lake, miles	91	57	99	247		41	47	88	77		609		
Shorelength of islands, miles	19	3	16	38		5	10	15	32+		390+		
Shore development, excl. islands	2.3	2.7	2.9	4.4		2.9	1.5	2.5	2.3		12.0		
Shore development, incl. islands	2.8	2.8	3.4	5.1		3.3	1.8	3.0	3.3		19.7		
Renewal time[b], days	5.3	2.4	4.1	12		2.0	600+		600[c]		6.5		

[a] Elevation to which the morphometric parameters are referable (i.e. at date of sounding, etc.).

[b] Based on mean annual discharge of Nelson River at Warren Landing and as routed through Playgreen Lake (Table 3), except for

[c] Based on mean annual fluctuation in water level, calculated on the assumption that ice jamming occurs every winter.

has a very flat bottom and a very low ratio of mean to maximum depth (Table 2). These relationships are also evident from the hypsographic curves (Figure 7).

The shorelines are irregular but, for the most part, not discordantly so. The shore development of both Playgreen (5.1) and Kiskittogisu (3.0) are slightly less than expected values for Canadian Shield lakes of comparable size (Koshinsky 1970). Only Cross Lake has a shore development which exceeds the expected value for a Canadian Shield lake of its size. Cross Lake is unique among these lakes in that its shoreline is predominantly bedrock controlled (Table 4).

The Nelson River at the outlet of Lake Winnipeg drains some 387,500 square miles and produces a mean annual discharge of 72,700 cubic feet per second (Manitoba Water Resources Branch Report, 1972). For ordinary mean monthly unregulated discharge, there is relatively little difference in the proportionate routing of flows through the East and West channels (Table 3). However at extremely high or low discharge from Lake Winnipeg, the proportion of flow in the East Channel is reduced.

Renewal times, as a consequence of the tremendous drainage area, are extremely short for those lakes receiving the direct flow of the Nelson River (Tables 2 and 3). On the basis of the mean annual discharge at Warren Landing (72,700 cfs), the entire volume of Playgreen Lake is equalled by its inflow every 12 days; that of the northern channel area of Kiskittogisu Lake in about 2 days. An estimate of the renewal time for Kiskitto Lake was derived from the mean annual surface level fluctuation (4.27 feet) as determined from the stage hydrograph given in the Manitoba Hydro (1972) report on Kiskitto Lake regulation.

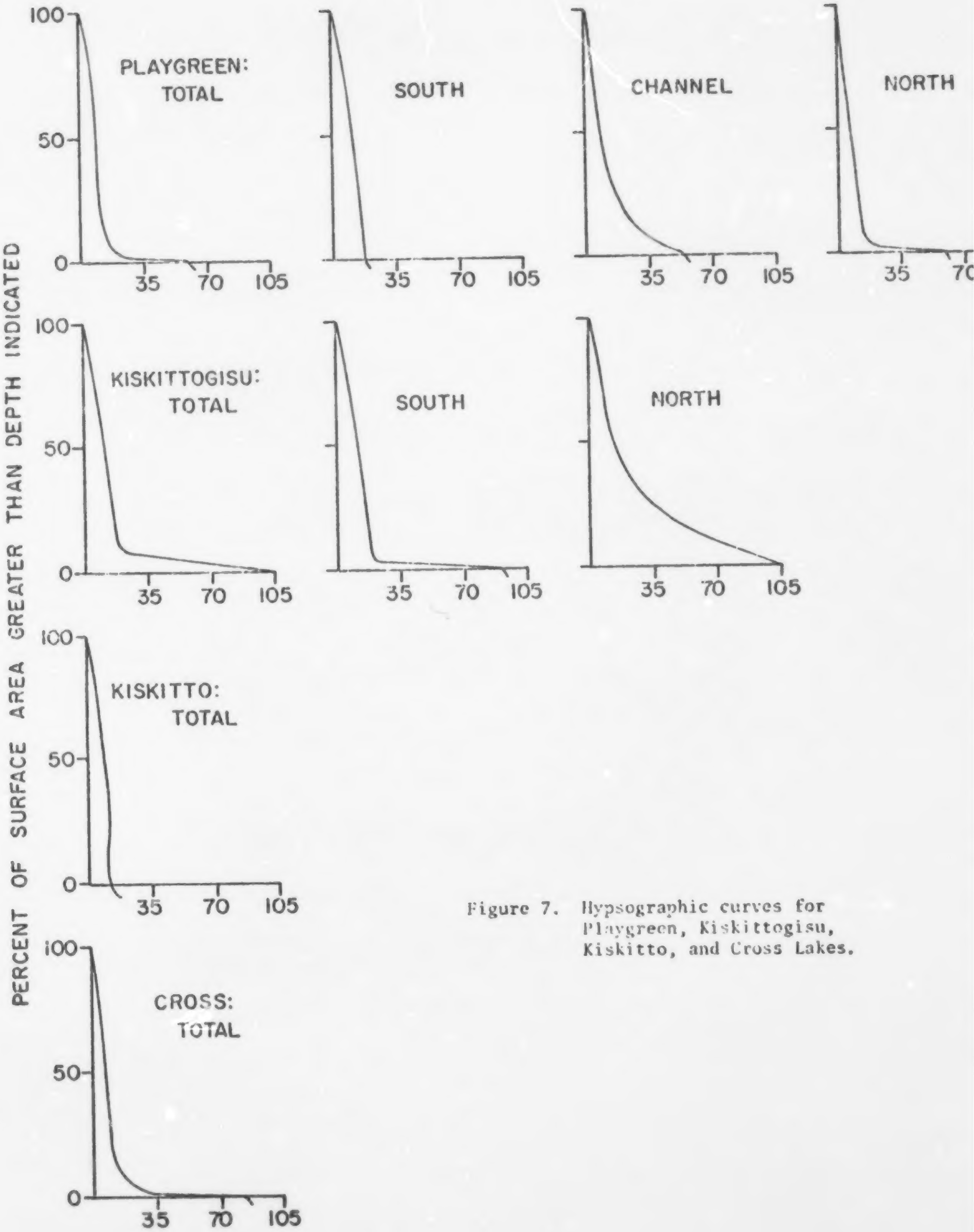

Figure 7. Hypsographic curves for Playgreen, Kiskittogisu, Kiskitto, and Cross Lakes.

Table 3. Routing of flows through Playgreen Lake (East and West Channels) in the unregulated condition for six discharge situations. Data from Ayles (MS 1973), based on Report of the Manitoba Water Resources Branch, 1972.

	Flow distribution		Renewal time (days) Playgreen L.		
	cfs	%	South	North and Channel	Whole Lake
A. Average annual flow					
East Channel	11,900	16			
West Channel	60,800	84	6.3	6.5	12.8
Total	72,700				
B. Average June flow[a]					
East Channel	15,500	17			
West Channel	75,500	83	5.1	5.3	10.4
Total	91,000				
C. Average February flow[b]					
East Channel	8,000	15			
West Channel	43,300	85	8.5	8.7	17.2
Total	53,300				
D. Maximum average flow[c]					
East Channel	28,700	20			
West Channel	116,500	80	3.3	3.4	6.7
Total	145,220				
E. Minimum average flow[d]					
East Channel	0	0			
West Channel	18,700	100	20.6	21.1	41.7
Total	18,700				
F. Maximum recorded flow[e]					
East Channel	23,400	13			
West Channel	158,600	87	2.4	2.5	4.9
Total	182,000				

[a] Based on highest average mean monthly discharge.
[b] Based on lowest average mean monthly discharge.
[c] Based on highest maximum mean monthly discharge.
[d] Based on lowest minimum mean monthly discharge.
[e] Based on 1966 flood conditions (Manitoba Hydro data).

The volume of water represented by this mean annual fluctuation (4.27 feet x 55,200 acres = 236 x 10^3 acre-feet)[1] was expressed on daily basis (÷ 365 = 646 acre-feet, = 326 cfs) to obtain a mean dai discharge equivalent. This procedure is very arbitrary because act exchange takes place over a much more restricted time period, and f other reasons as well. On this basis, however, and at the volume p taining at the time of sounding, Kiskitto Lake would be "renewed" e 600 days, on average. The south basin of Kiskittogisu Lake, with a twice the volume of Kiskitto Lake but with a more active connection with the Nelson River, probably renews at a comparable rate, i.e. a once every 2-3 years.

6.2 Shorelines:

On the basis of the shoreline classification put forth by Dr. Newbury and his colleagues (University of Manitoba, 1973), an atte has been made to identify and quantify the most suitable shoreline habitats with regard to requirements of the major economic fish sp Although the Newbury classification deals more specifically with s line and backshore characteristics than with offshore substrates a depths, it seems that the appropriate extrapolations of characteri can be made with fair confidence.

The extent of the particular key shoreline types in those lak that were classified in this manner is summarized in Table 4. The following criteria were employed in the analysis:

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[1] The assumption is made, as prescribed in the Manitoba Hydro r that ice jams in the West Channel operate to maintain water l in Kiskitto Lake in winter. Without this factor, annual fluc ations would be much greater.

Table 4. Distribution of shoreline types[a] in the Lake Winnipeg outlet lakes, with special reference to those shoreline types of particular relevance to economic species of fish.

Lake	Miles of shoreline according to shoreline type[a]										% contribution by particular type groups	
	13	15	22	24	26	27	28	31	Other	Total	13+ 22[b]	15+24+26+ 27+28+31[c]
South Playgreen	16	1	2	0	43	25	24	14	1	126	14	85
North Playgreen	74	7	0	0	32	12	11	15	16	167	44	46
Little Playgreen	43	4	0	0	21	1	24	0	11	104	41	48
Kiskittogisu	23	6	0	0	25	4	0	11	5	74	31	62
Kiskitto	27	1	0	0	17	0	4	9	2	60	45	52
Pipestone	8	26	0	1	0	0	6	0	2	43	19	77
Cross	392	224	2	22	2	7	29	1	148	827	48	34
West Channel	86	24	0	0	12	6	9	0	21	158	54	32
East Channel	33	42	2	0	27	18	9	0	42	173	20	55

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[a] Classification according to Univ. Manitoba Rept. 1973. See text for abbreviated descriptions.

[b] Important (by inference) for reproduction of whitefish and walleye.

[c] Important (by inference) for northern pike, and for rearing of goldeye.

[d] Includes channel between South and North Playgreen.

1) Whitefish: It is generally accepted that lake whitefish have a strong shoreline interaction during the reproductive period in their life history, and that they are not directly dependent on shorelines at other times. Observations at Southern Indian Lake (K. Weagle, personal communication) indicate that among the shorelines available in the Outlet Lakes, those providing bedrock, broken rock, and coarse gravel substrates would be most suitable for whitefish spawning. Faber (1970) has also noted that early young-of-the-year whitefish tend to congregate along such shores. Under the Newbury clas sification, the preferred substrates would seem most likely t occur along shoreline Types 13 (irregular, low bedrock shoreline) and 22 (coarse sediments with shallow underlying ice-contact material).

2) Walleye: The same substrate characteristics which best accommodate spawning whitefish also tend to be those which a most satisfactory for shore-spawning walleyes (Johnson 1961) Walleyes are not obligatory shore-spawners; in fact most of their reproduction may take place in tributary streams if su are available. In contrast to whitefish, walleyes make substantial use of the inshore environment at all ages. In la of the type here encountered, adults would be most expected along shores which are bedrock-controlled (Type 13).

3) Northern pike: This species is very cosmopolitan in it distribution, both among and within lakes. However the spa distribution commonly shows a strong inverse correlation wi depth (Koshinsky MS 1972) and a positive correlation with

aquatic vegetation. Pike spawn in shallow water (usually 20 inches or less) and most typically in association with vegetation or vegetative debris (Toner MS 1966). In Newbury's classification, Type 24 (low alluvial shoreline) would seem to be most suitable for pike in all life history stages. Extensive utilization by pike would also be anticipated for shorelines of Type 15 (low bedrock-controlled shoreline), Type 26m (treed muskeg shoreline, with offshore marsh), Type 27m (low shoreline in coarse sediments, with offshore marsh), Type 28m (low willowed shoreline, with offshore marsh) and Type 31 (fen shoreline: floating meadow). The latter may, in fact, be the most preferred type for pike spawning.

4) Goldeye: This species is characteristic of turbid, delta locales and its post-reproductive habitat preferences are not readily assessed in terms of shoreline types. However Sunde (personal communication) has concluded that goldeye are most successful where the young have access to shallow, marshy rearing sites during their first summer. Shoreline Types 24, 26m, 27m, 28m, and 31 of Newbury's classification (see above) would probably best accommodate goldeye reproduction.

Correlation of the extent of the key shoreline categories with the actual fish populations in the lakes is attempted in a later section of this report.

6.3. Physical-chemical conditions:

As made clear by Stockner (MS 1973), these lakes remain essentiall isothermal (same temperature top to bottom) during the ice-free season.

Only in a few isolated bays did Stockner note weak and temp stratification in his observations at Playgreen and Kiskit during summer and autumn. Schlick (personal communication stratification in the south part of Kiskittogisu Lake in e a maximum observed differential, from surface to bottom, o ever bottom temperatures even in this situation were relat (14.4°C) indicating considerable mixing and a generally we cation potential. Two temperature profiles in Kiskitto La June 1972 showed even less thermal gradient (1.7°C gradien to bottom). Driver and Doan (personal communication) foun pletely homothermous conditions throughout Cross Lake in J of 1965, even at the deepest station (35 feet).

The highest surface or near-surface temperatures reco lakes during the periods of observation were as follows:

Lake	Highest observed temp. °C	Period of
Playgreen	19.8	July-Oct
Kiskittogisu	17.7	July-Oct
Kiskittogisu	19.4	July 197
Kiskitto	16.7	June 197
Cross	18.3	June-Jul

These maxima clearly reflect the cold continental cli eristics, and could be expected to exert some definite neg on biological productivity. On the other hand, the lack o stratification would be a positive factor in this regard.

Temperatures in the south basin of Playgreen Lake dur July to October in 1971 were generally warmer than in the Playgreen or in Kiskittogisu Lake (Table 5). Lowest tempe encountered in the south part of Kiskittogisu Lake, which isolated from the Nelson River discharge. One-meter tempe

Table 5. Distribution of surface[a] temperatures in Playgreen and Kiskittogisu Lakes, 1971. Values are means of all observations made within the particular time period in the particular region[b]. Numbers of observations are given in brackets. Values for Lake Winnipeg for 1969 are also given[c].

	Lake Winnipeg	Region 1	2	3	4	
July 22-30	19.6(16)	16.5(2)	18.0(2)	17.5(3)	16.1(4)	15
Aug. 1-15	- (0)	17.5(13)	- (0)	16.7(7)	15.4(8)	14
Aug. 16-31	- (0)	18.1(4)	- (0)	17.2(4)	16.3(4)	16
Sept. 1-15	17.4(12)	15.4(4)	15.4(5)	16.5(2)	13.0(4)	
Sept. 16-30	- (0)	11.3(4)	- (0)	- (0)	12.0(2)	12
Oct. 1-15	8.4(15)	8.7(6)	8.8(2)	8.3(4)	7.4(4)	6
Oct. 16-21	3.3(7)	6.2(4)	- (0)	4.6(3)	- (0)	

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[a] Actually taken at a depth of 3 feet.

[b] See Figure 2 for designation of regions.

[c] Data from Brunskill (personal communication).
Values are for north basin of Lake Winnipeg, north of Long Point.

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5(2)
2(2)
8(2)
(0)
5(4)
2(2)
(0)

the north basin of Lake Winnipeg are also given (Table 5) exc
they are unfortunately for a different season. Nevertheless
apparent that the waters of Lake Winnipeg exert a general war
effect on the Outlet Lakes during summer-autumn. This effect
ficiently transmitted by the very rapid renewal times (Table
on-channel basins. As noted by Stockner (MS 1973) the massiv
inertia of Lake Winnipeg significantly retards autumn cooling
Outlet Lakes; presumably it has the opposite effect in spring

With regard to open-water dissolved oxygen conditions, S
(loc.cit.) found that saturation or supersaturation prevailed
stations at all depths at all times in Playgreen and Kiskitto
Driver and Doan (personal communication) found essentially sa
oxygen conditions in the bottom waters of Cross Lake (35 feet
July.

Stockner conducted a winter survey of dissolved oxygen c
in Playgreen and Kiskittogisu Lakes, sampling 106 stations at
intervals surface to bottom over the period 21 March to 13 Ap
It is considered that 5 parts per million dissolved oxygen wo
quately meet the requirements of the indigenous fish fauna (e
special reproductive requirements), and concentrations lower
were encountered at only 11 stations. The majority of statio
80-98% oxygen saturation. Lowest concentrations were invaria
countered on the bottom, so that of the 11 stations with less
parts per million, six had "adequate" levels nearer the surfa
the worst of these stations (35d and 40b), a winter oxygen de
rate of 0.096 ppm per day is implied (over approximately 150

The distribution of the 11 stations with critically low oxygen values, with the lake Area in which they are situated given in brackets, was as follows:

Oxygen concentration, ppm		
0.5 - 0.9	1.0 - 2.4	2.5 - 5.0
32d (3)	22d (2)	27c (3)
35d (3)	40a (3)	35c (2)
40b (3)	40d (3)	39d (3)
		40 (3)
		43d (3)

The locations of these stations can be noted by reference to the maps, Figure 2. Without exception, they were located in bays or marshy inlets removed from the main channel of the Nelson River. The majority were in shallow water next to shore. All of these stations occurred in either Area 2 or 3. These areas have the greatest number of isolated bays (Figure 2), which is also reflected in their shore development values (Table 2). H_2S odor and slight brown color were consistent features at the stations showing oxygen depletion.

The very favorable winter oxygen conditions in Area 1 (South Playgreen) and Area 4 (Kiskittogisu channel) can be interpreted as a reflection of the constant and heavy influx of water from Lake Winnipeg, combined with the relatively regular shoreline. However the persistence of saturation or near-saturation conditions in the main basin of Kiskittogisu Lake (Area 5) cannot be attributed to the influence of Nelson River exchange, and this suggests that this exchange may not in fact be the primary factor ensuring high winter oxygen in any of these lakes. Probably of greater significance is a suspected low rate of primary production and accumulation of readily decomposible organic matter during the growing season. Localized inshore depletion under this assumption would be attributed primarily to decomposition of allochthonous organic materials originating outside the lakes. This general proposition is supported by the situation in Kiskitto Lake which is extremely shallow but which regularly carries enough oxygen over winter to support a diverse fish fauna. Kiskitto Lake is very turbid (Table 6) and is even more remotely connected to the Nelson River than is Kiskittogisu Lake. Stockner conducted winter oxygen analyses at two stations in Kiskitto Lake during his 1971 survey (station locations unknown) and found near-saturation conditions. This could, however, be partly a consequence of water back-up into Kiskitto Lake under winter ice-jamming conditions, a phenomenon not fully known or understood at the present time.

Sunde (personal communication) found that nearly half of 57 stations sampled for late-winter oxygen in nearby Moose and Cedar Lakes had values below 5 ppm; most of these had less than 1 ppm. These lakes are in many respects similar to the Lake Winnipeg Outlet Lakes (Webb 1965), but they are situated on glacial till rather than on glacio-lacustrine deposits (Weir and Mathews 1971). However Sunde did find high late-winter oxygen values in Talbot Lake despite average depths of only about 10 feet. Talbot Lake lies adjacent to Cedar Lake in the Grand Rapids forebay area, but has much less active water exchange.

Some indication of the relative transparency of these waters is provided by Secchi disc readings recorded by Stockner (MS 1973), and by brief surveys conducted by Manitoba Department Mines, Resources and Environmental Management. The available data in this regard are summarized in Table 6.

Table 6. Summary of Secchi disc readings obtained in the Lake Winnipeg Outlet Lakes.

	Year	No. measurements	Secchi disc values, ft	
			Mean	Range
North basin of Lake Winnipeg[a]	1969	72	4.6	4.1-5.9
Playgreen	1970[b]	21	1.6	0.6-2.7
Playgreen	1971[b]	80	1.8	0.5-4.7
Kiskittogisu	1970[b]	7	1.0	0.7-1.5
Kiskittogisu	1971[b]	41	1.8	1.0-4.8
Kiskittogisu	1972[c]	4	2.5	2.0-3.0
Kiskitto	1972[c]	10	0.7	0.6-1.1
Cross	1965[c]	10	2.5	1.0-4.5

[a] Based on measurements in the area between Berens Island and Warren Landing, between June and September (Brunskill, personal communication).

[b] Stockner MS 1973.

[c] Schlick and Doan, personal communications.

It is apparent that the primary source water, Lake Winnipeg, although itself noted for its high turbidity, is much more transparent than the water in the Outlet Lakes. This implies a significant uptake of suspended matter within the Outlet Lakes which, on the basis of the characteristic grey-brown color, is undoubtedly derived through wind action on the glacio-lacustrine shore and bottom deposits. Although Stockner noted somewhat higher transparency values in those Playgreen Lake stations situated nearest Warren Landing, this gradient is quickly overcome so that mean values for the three basins of Playgreen Lake are very similar. Mean Secchi disc values for Kiskittogisu Lake were the same as for Playgreen Lake in 1971, but were significantly lower (t-test) than for Playgreen Lake in 1970. It is noted that mean wind speeds (The Pas station)[2] were somewhat higher in 1970 than in 1971 over the sampling period (10.7 versus 9.9 miles per hour during September-October); this suggests a mechanism for relatively greater internally-induced turbidity in 1970. It is not surprising that this effect would be observed in Kiskittogisu Lake, with the slow water exchange in its main basin (Table 2). Playgreen Lake, with its very rapid water exchange, exhibited only slightly lower transparency in 1970 than in 1971 (Table 6).

The Kiskittogisu-Kiskitto Secchi disc readings taken by Schlick (personal communication) in 1972 are probably not comparable with the earlier Playgreen-Kiskittogisu values for various reasons, but should be more or less comparable among themselves. In any event, the recorded differences are so great that it seems unquestionable that Kiskitto Lake is much less transparent than Kiskittogisu. The maximum Secchi disc value recorded in Kiskitto Lake was only 13 inches, and it is clear that this situation would be highly limiting to primary production. It is most unfortunate that no algal standing crop values are available for interpretation; however all indications again are that the high turbidity of Kiskitto Lake is induced not by algae, but by wind action on its sediments and shores. Being even more remotely connected to the flow of the Nelson River than is Kiskittogisu Lake (Figure 1), this impact is very much manifested.

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[2] Canada Department of Transport. Monthly record of meteorological observations. Toronto.

The average transparency in Cross Lake is higher than in those Outlet Lakes farther upstream (Table 6). However closer examination reveals that readings at the three stations along the actual Nelson River discharge corridor were comparable to the other lakes (mean value at Stations 8, 9, and 10 = 1.5 feet). Considerably higher Secchi disc values were obtained in the eastern portion of Cross Lake which is less subjected to the Nelson River influence, and where the shorelines are primarily bedrock-controlled (Shoreline Types 13 and 15, Table 4).

Manitoba Hydro recently initiated an extensive program to monitor inshore suspended sediment characteristics along 23 transects involving some 200 stations in the area of Warren Landing and off the ends of the 2-mile and 8-mile channel locations in Lakes Winnipeg, Playgreen, and Kiskittogisu. Cursory inspection of some 10,000 analyses indicated (to the writer) that no firm general conclusions could yet be reached from these data as to the comparative background sediment load of the water in these inshore locations.

Chemical analyses involving a wide variety of parameters have been performed on waters from the Lake Winnipeg Outlet Lakes by several investigating agencies over the past few years. The more pertinent available findings are summarized in Table 7. In addition, more comprehensive

Table 7. Summary of pertinent chemical analysis results, Lake Winnipeg Outlet Lakes. All analyses are from surface or near-surface samples. Values are mg/liter (ppm) unless otherwise indicated.

	From M. Morelli (personal communication). See Appendix A			From Stockner MS 1973		Fisheries Research Board			From Man. Dept. Mines, Res., Env. Management				
												Cross Lake	
	Warren Landing	Jenpeg	Eve Rapids	Playgreen Lake	Kiskit-togisu Lake	Playgreen Lake	Kiskit-togisu Lake	Kiskitto Lake	Playgreen Lake	Kiskit-togisu Lake	Kiskitto Lake	East	West
Date	6-9-72	(July-December 1972)		(August-October, 1971)		(14 December 1972)			Aug. '71	July '72	June '72	(June-July '65)	
pH	7.5	8.0	8.1	7.6	7.7	8.1	8.2	8.2	8.0	-	-	7.8	7.8
Turbidity	35	36	28	-	-	118	20	12	-	-	-	-	-
Spec. conductivity, μmho/cm	317	316	318	301	301	343	374	364	255	-	-	-	-
Total dissolved solids	-	-	-	228	226	230	265	259	197	212	183	115	133
Calcium	31	31	31	-	-	34	38	46	32				
Magnesium		-	-	13	13	14	15	14	11				
Sodium	24	18	16	15	15	19	20	14	17				
Potassium	4.8	2.2	2.2	-	-	3.3	3.3	2.5					
Silica (SiO_2)	0.8	1.2	1.2	0.74	0.34	0.12	0.86	2.05					
Chloride	36	20	17	15	15	19	22	11	16				
Sulfate	28	27	30	-	-	35	35	27	26				
Bicarbonate	116	123	122	136	137	-	-	-	135				
Mercury, μg/l	0.13	0.08	0.09	-	-	-	-	-					
Zinc	0.017	0.002	0.001	-	-	-	-	-					
Copper	0.003	0.002	0.004	-	-	-	-	-					
Total nitrogen (N)	-	0.78	0.67	-	-	0.65	0.41	0.32	-				
Dissolved nitrogen (N)	-	-	-	-	-	0.410	0.365	0.290	-				
Nitrate nitrogen (N)	-	-	-	<0.05	<0.05	0.015	0.016	0.020	-				
Total phosphorus (P)	0.043	0.036	0.035	-	-	0.027	0.026	0.023	0.045				
Dissolved phosphorus (P)	-	-	-	0.040	0.051	0.023	0.019	0.016	-				
Ortho phosphorus (P)	<0.003	0.005	0.004	-	-	-	-	-	-				

analysis results from six stations sampled by the Manitoba Environmental Protection Branch are given in Appendix A.

As would be anticipated, the Lake Winnipeg discharge, as sampled at the Warren Landing station, exerts the main controlling influence on the chemical parameters of these lakes. It establishes the basic total dissolved solids framework of about 230 ppm, and a slightly alkaline pH. Within this framework there is tendency for pH, conductivity, TDS, and many of the macro-ions to increase from Lake Winnipeg through Playgreen and Kiskittogisu Lakes, then to decrease again into Kiskitto and through Cross Lake. The heavy metals (notably mercury and zinc), and the nutrient ions and complexes, generally show the opposite tendency, i.e. they appear to be retained to varying degrees in passage through Playgreen and Kiskittogisu Lakes. These tendencies must reflect interactions of the various ions with the lake sediments. In the case of Cross Lake, with less soluble surficial materials in the drainage basin of the east arm of the lake, a marked dilution tendency becomes apparent. As noted by Stockner, ion and nutrient concentrations in the Lake Winnipeg Outlet Lakes are two or more times as high as in the Churchill River System. This reflects the fact that the Nelson River, to this point, drains primarily unconsolidated glacial tills.

Nutrient loading values to Playgreen Lake were calculated on the basis of the mean annual discharge at Warren Landing (72,700 cubic feet per second), in conjunction with the average nutrient concentrations observed by Brunskill (personal communication) in the north basin of Lake Winnipeg (north of Long Point). It might be noted that very little temporal variation was found in the Lake Winnipeg data over the June-

October (1969) sampling period, so that the calculations here employed are probably quite representative. The following loadings were derived:

Parameter	Total annual load to Playgreen Lake	
	lb x 10^6	gm/m^2
Total phosphorus (P)	4.22	2.96
Dissolved phosphorus (P)	2.58	1.81
Total nitrogen (N)	52.2	36.6
Dissolved nitrogen (N)	43.3	30.4

In view of the rapid water exchange, it is likely that only a fraction of even the dissolved component of these loadings would have relevance to the productivity of these lakes. Even on this basis, however, these are astronomical loading values which can only be interpreted in the full context of the extremely rapid water renewal rates.

The notably higher turbidity in Playgreen Lake than at the other three stations observed in the Fisheries Research Board winter sampling program (Table 7) is of some interest. This suggests a completely opposite trend to the summer Secchi disc readings (Table 6). The Playgreen sample in question was taken just below a turbulent open-water area, which probably accounts for the discordantly high turbidity.

6.4. Bottom fauna:

Bottom fauna in the Lake Winnipeg Outlet Lakes has been sampled under three different studies. Ayles (MS 1973) has analysed and reported the results of 173 Ponar grab samples taken in 1971 in the Manitoba Hydro-sponsored program in Playgreen and Kiskittogisu Lakes. Some 30 samples taken under the same program in 1970 were not analysed in detail because cursory inspection indicated that they were not reliable. Schlick (personal communication) has made available enumerations from 56 Ekman dredge samples taken at Kiskittogisu and Kiskitto Lakes in 1972.

Table 8. Standing crop and composition of bottom fauna (zoobenthos) in the Lake Winnipeg Outlet Lakes. Values are weighted according to percent areas of depth zones.

	Playgreen				Kiskittogisu				Kiskitto	Cross
	South	Channel	North	Total	North	South	Total	South		
Source[a]	Ayles	Ayles	Ayles	Ayles	Ayles	Ayles	Ayles	Schlick	Schlick	Doan
Sampling period	(18 July	- 21	October,	1971)	(26 July-	13 Oct.	1971)	July	June	June
No. samples	69	12	34	115	35	23	58	24	32	9
Standing crop, lb/acre	17.3	6.3	20.1	16.8	5.8	3.4	3.8	-	-	-
No. organisms/sq.ft.	46.7	40.6	38.9	43.0	19.7	19.4	19.5	39.1	28.8	101.5
Numerical composition, numbers per square foot										
Mayflies:										3.0
Hexagenia	6.6	0.6	3.1	4.5	5.0	9.2	8.5	5.5	20.0	-
Ephemera	2.5	2.5	0.1	1.6	0.0	0.0	0.0	0.5	0.0	-
Chironomids	1.3	+	2.0	1.4	1.6	0.6	0.8	2.4	2.5	22.9
Chaoborus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2
Caddis	1.1	1.0	0.4	0.8	0.0	0.0	0.0	0.0	0.0	0.0
Amphipods:								5.9	0.0	39.6
Pontoporeia	18.7	13.1	22.1	19.1	3.9	6.4	6.0	-	-	-
Gammarus	0.0	0.0	0.0	0.0	0.6	0.0	0.1	-	-	-
Hyallela	0.0	0.0	0.0	0.0	0.1	0.0	+	-	-	-
Snails	0.7	0.0	+	0.4	0.2	0.1	0.1	10.4	1.8	2.5
Sphaeriids:								13.9	4.0	19.8
Sphaerium	14.1	20.7	10.5	13.7	6.9	3.1	3.7	-	-	-
Pisidium	1.0	2.6	0.4	1.0	1.0	0.0	0.2	-	-	-
Other[b]	0.7	0.1	0.3	0.5	0.4	0.0	0.1	0.5	0.5	13.5

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[a] Ayles MS 1973; and personal communications from R.O. Schlick, and K.H. Doan.

[b] Includes (variously) leeches, nematodes, oligochaetes, ostracods.

Doan (personal communication) has provided similar data for nine Ekma dredgings taken from Cross Lake in 1965. Again, the stations visited shown on the maps, (Figures 1, 2 and 6). Sieving techniques were not always specified and the results from Kiskittogisu Lake (Table 8) sugg that the Manitoba Hydro sampling (Ayles MS 1973) may have been only ab half as efficient, in terms of organisms recovered, as the sampling un taken in the Manitoba Government studies.

Amphipods (particularly *Pontoporeia affinis*), sphaeriids (particu larly *Sphaerium* sp.), and large burrowing mayfly nymphs (*Hexagenia* sp and *Ephemera* sp.) generally dominate the bottom fauna of these lakes (Table 8, Figure 8). In these respects, the fauna is very reminiscent that described by Bajkov (1930) for the mud-bottom "whitefish grounds" Lake Winnipeg. Except for the scarcity of chironomid larvae, this fau also resembles that described by Rawson (1957, 1960) for Churchill-Riv lakes in Saskatchewan. The most chironomids were encountered in Kiski and Cross Lakes, perhaps because samples there were taken in June befo chironomids emerged. Most of the Cross Lake specimens were taken at a single sampling station (1A) far removed from the main flushing action the Nelson River (Figure 6), and it might be noted that Rawson (1960) recorded an inverse relation between chironomid abundance and lake ren time among the Churchill-River lakes. Those that flushed in two weeks less had as little as 3% chironomids, compared with up to 55% chironom in those that flushed in a month or more. There is also the possibili (which may be related to flushing and associated transport of organism that chironomid distribution in a chain of lakes such as these is phys cally enhanced in the downstream direction. This proposition would be ported by the fact that chironomids were found to be the main componen

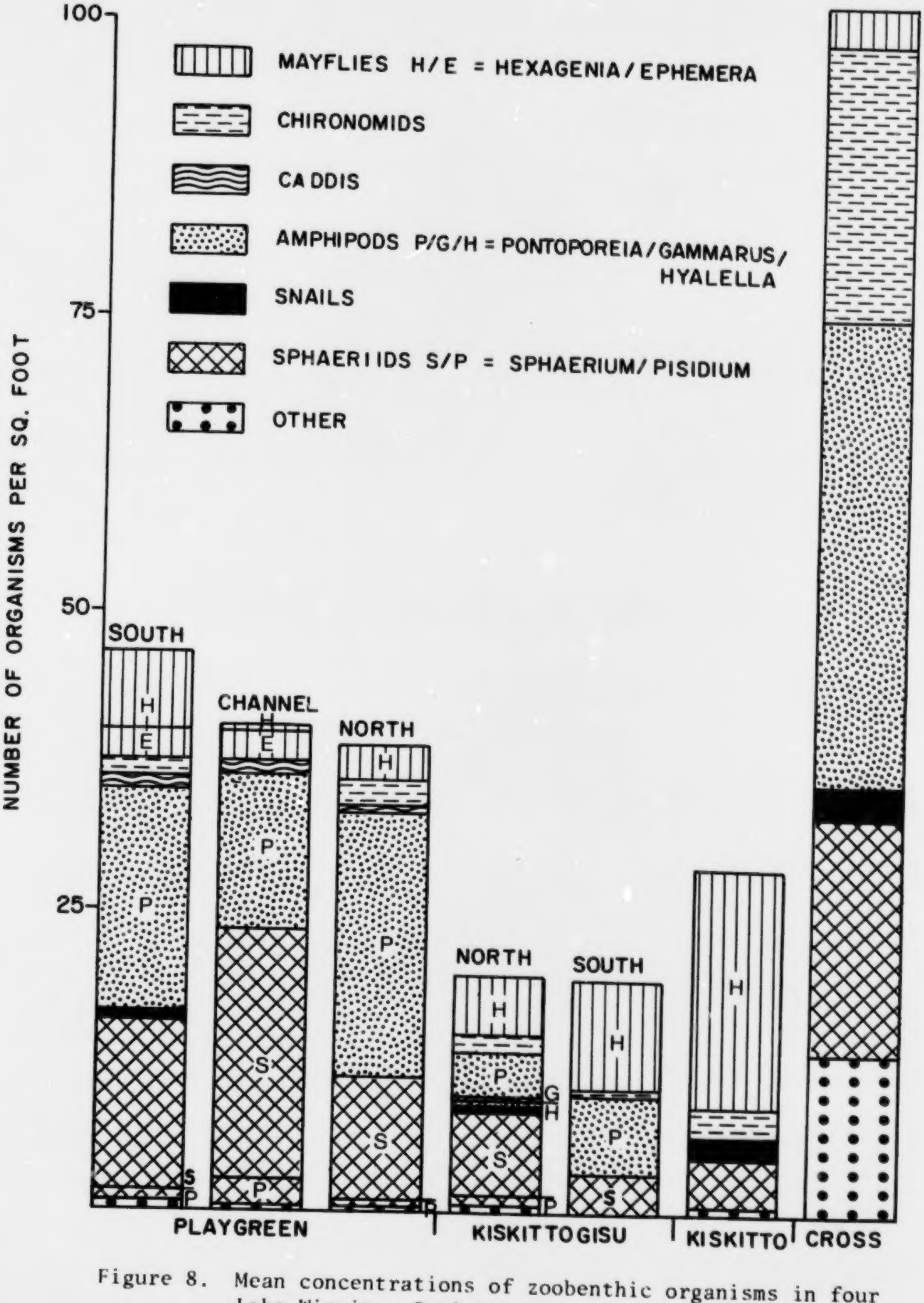


Figure 8. Mean concentrations of zoobenthic organisms in four Lake Winnipeg Outlet Lakes.

of the benthic fauna in the Kettle and Kelsey reservoir areas which are still farther downstream (J. Crowe, personal communication). Alsc if renewal time were the only criterion, high chironomid densities would be anticipated in Kiskitto Lake and the main basin of Kiskittog Lake, but this was not observed.

Other qualitative differences in zoobenthos observed within and among the Outlet Lakes include the following:

a) Caddis fly larvae confined to Playgreen Lake, and apparent dependent on direct interaction with water from Lake Winnipeg. This may be an indication of more favorable water quality para meters and/or of associated algal food material.

b) Amphipods (mainly *Pontoporeia affinis*, but this species n confirmed from Cross Lake) collected in all the lakes except Kiskitto. Probably the very shallow depth coupled with the e tensive water level fluctuations are the prohibiting factors here.

c) *Chaoborus* found only in Cross Lake. As with the other dipteran group (chironomids) this suggests the same tendency enhanced abundance in the downstream direction.

d) Sphaeriids (both *Sphaerium* and *Pisidium*) favored by rapi water exchange conditions as evidenced by distribution withi Playgreen and Kiskittogisu Lakes.

e) The mayfly genera *Hexagenia* and *Ephemera* inversely distr buted, with *Ephemera* favored by rapid water exchange conditi (e.g. Playgreen Channel area), and *Hexagenia* more abundant the more lentic situations (e.g. Kiskitto and Kiskittogisu This distribution pattern coincides precisely with the stru adaptations of these organisms as these adaptations in turn dictate substrate preferences (Eriksen 1964).

The significance of these qualitative differences in the benthi fauna is difficult to assess from the fishery point of view without concurrent information on fish stomach contents. Observations on Churchill River lakes (e.g. Koshinsky MS 1971) suggest that the larg burrowing mayflies, when they assume so predominant a role in the benthic fauna as they do in the Lake Winnipeg Outlet Lakes, would be a very significant element in the diet of whitefish and walleye. The abundance of Pontoporeia and sphaeriids would also be expected to pl a strong role in whitefish productivity. An important gap in the normal whitefish diet would be posed by the scarcity of chironomid larvae.

Whatever the general shortcomings of the quantitative benthic da certain internal comparisons can still be made. Thus it is apparent that Playgreen Lake has a much heavier (about 4 times) bottom fauna t Kiskittogisu Lake. Furthermore, the channel sections of both Playgre and Kiskittogisu Lakes, with their very rapid renewal times of about days (Table 2) have a considerably lighter benthos than do the North and South basins of Playgreen Lake. This is linked to reduced numbe of Pontoporeia and, in the Playgreen Channel, to reduced numbers of Hexagenia as well. The south basin of Kiskittogisu Lake, on the othe hand, even though it would appear to be flushed much more slowly, has a still lower standing crop of benthos. This would indicate a signif cant disbenefit of the substantially reduced water exchange from the Nelson River. This proposition finds further support as regards Kiskitto Lake, although the only basis for comparison is the numerica density compared with Kiskittogisu Lake (Table 8). It should be re emphasized that while reduced flushing appears detrimental to Ephem it clearly favors Hexagenia, the other genus of this important mayf group.

The overall magnitude of the standing crop of bottom fauna org isms in the Lake Winnipeg Outlet Lakes is difficult to assess from available data. Numbers and weights of these organisms as sampled averaged only about 50 individuals per square foot, and about 10 po per acre dry weight. These values seem generally too low to be cor tent with other indicators of productivity; TDS, for example, avera about 230 ppm among these lakes (Table 7). Webb (1965) by way of c parison, found 23.4 lb/acre dry weight of bottom fauna in Cedar Lak the Saskatchewan River Delta prior to impoundment. Cedar Lake, als shallow and subject to rapid flushing, had TDS from 230 to 310 ppm Secchi disc values from 0.3 to 4.5 ft. Koshinsky (MS 1968) found a average of 165 organisms per sq. ft, weighing 11 lb/acre dry weigh among 28 relatively unproductive Shield lakes (mean TDS 65 ppm) at parable latitude in Saskatchewan. Rawson (1960) found from 129-41 organisms per sq. ft. and 23-57 lb/acre dry weight among five Chur River lakes with mean TDS about 140 ppm and renewal times as short 7 days. Ayles (MS 1973) has pointed out the probable shortcomings the benthic sorting techniques employed in the Outlet Lakes studie

6.5. Fish populations:

Fish populations in the Outlet Lakes have been sampled and e uated by the Manitoba Government (Cross Lake in 1965, Playgreen La 1971, and Kiskittogisu-Kiskitto Lakes in 1972), and by Manitoba Hy (Playgreen and Kiskittogisu Lakes, 1970-1971).

6.5.1. Composition of the fish fauna:

These lakes harbor a very diverse and complicated fish fauna, which includes at least 21 species (Table 9). This list is undoubtedly very incomplete, particularly as regards distribution among the individual lakes. Species which are of significance for commercial fishing and domestic consumption involve two major categories:

a) Preferred species: Lake whitefish, walleye, sauger, northern pike, goldeye, perch, and sturgeon.

b) Coarse fish species: Cisco, burbot, carp, and four species of suckers: white, longnose, shorthead redhorse, and quillback.

Although quite a number of the species listed may also be taken by sport-fishing gear, only two of those present in these lakes (walleye and pike) generally contribute significantly to sport fish catches in this general area.

6.5.2. Fish standing stocks:

As noted above, experimental gillnetting data are available for Playgreen, Kiskittogisu, Kiskitto, and Cross Lakes. The Province of Manitoba sampling results (Table 10) are the more extensive geographically, covering all four lakes. The Manitoba Hydro data (Table 11) are more intensive, but are for Playgreen and Kiskittogisu Lakes only. Both sets of data were employed to derive comparative inter-lake estimates of standing stocks, growth, and condition. The Manitoba Hydro results were used to assess population characteristics and movement of fishes among the five areas of Playgreen-Kiskittogisu.

Comparative evaluation of results from the different studies cannot be done with high confidence because of inconsistencies of gear (Table 1), timing, and other sampling characteristics. Nevertheless,

Table 9. Known occurrence of fish species in the Lake Winnipeg outlet lakes[a].

		Category[b]										
		Commercial	Sport	Coarse	Forage	Playgreen	Kiskittogisu	Kiskitto	Pipestone	Cross	Drunken	Walker
Lake whitefish	Coregonus clupeaformis	X				X	X	X	X	X	X	X
Walleye	Stizostedion vitreum	X	X			X	X	X	X	X	X	X
Sauger	Stizostedion canadense	X				X	X	X		X		
Cisco (tullibee)	Coregonus sp.			X		X	X	X		X		X
Burbot	Lota lota			X		X	X	X		X		
Northern pike	Esox lucius	X	X			X	X	X	X	X	X	X
Yellow perch	Perca flavescens	X	X			X	X	X		X	X	
White sucker	Catostomus commersoni			X		X	X	X		X		
Longnose sucker	Catostomus catostomus			X		X	X					
Shorthead redhorse	Moxostoma macrolepidotum			X		X	X	X				
Quillback sucker	Carpiodes cyprinus			X				X				
Carp	Cyprinus carpio			X				X				
Goldeye	Hiodon alosoides	X						X	X	X	X	
Lake sturgeon	Acipenser fulvescens	X				X				X		
Johny darter	Etheostoma nigrum				X		X					
Iowa darter	Etheostoma exile				X		X					
Ninespine stickleback	Pungitius pungitius				X		X					
Brook stickleback	Culaea inconstans				X					X		
Mottled sculpin	Cottus bairdi				X		X					
Emerald shiner	Notropis atherinoides				X		X			X		
Spottail shiner	Notropis hudsonius				X					X		

[a] Based on personal communications from R.O. Schlick and K.H. Doan, and on commercial fishing statistics.

[b] Crude characterization only. Some species could fit other categories than those indicated.

Table 10. Overnight catch (No., and lb round weight) of fish species per gang of 50-yard gillnets in four of the Lake Winnipeg Outlet Lakes. Data are from Province of Manitoba (Schlick and Doan, personal communications). For details of gillnet specifications, see Table 1.

Lake:	Playgreen			Kiskittogisu			Kiskitto			Cross		
Period:	August 1971			July 1972			June 1972			June-July 1965		
No. sets:	34			12			16			4		
	No.	lb	% wt.	No.	lb	% wt.	No.	lb	% wt.	No.	lb	% wt.
Whitefish	11.2	24.4	33.0	22.7	41.8	17.9	8.2	17.3	13.8	14.5	43.3	15.4
Walleye	6.4	10.4	14.1	21.8	32.2	13.8	35.1	40.1	32.1	38.0	76.4	27.2
Sauger	0.4	0.8	1.1	0.1	0.1	+	0.1	0.1	0.1	0.3	0.4	0.2
Cisco	0.4	0.6	0.8	0.7	0.4	0.2	0.6	0.7	0.6	47.2	72.3	25.7
Burbot	0.3	0.7	0.9	1.9	4.3	1.8	0.3	0.7	0.6	1.0	5.5	2.0
Pike	4.5	9.9	13.4	4.5	9.5	4.1	5.0	10.0	8.0	19.5	56.4	20.1
Perch	1.7	1.7	2.3	0.1	0.1	+	0.7	0.4	0.3	0.5	0.6	0.2
White sucker	5.8	15.5	21.0	61.9	144.7	61.9	16.0	44.8	35.8	8.5	25.9	9.2
Longnose sucker	3.0	9.0	12.3	0.2	0.5	0.2	0.0	0.0	0.0	0.0	0.0	0.0
Redhorse sucker	0.3	0.8	1.1	0.1	0.2	0.1	1.3	2.7	2.1	0.0	0.0	0.0
Quillback sucker	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.0	0.0	0.0
Carp	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.0	0.0	0.0
Goldeye	0.0	0.0	0.0	0.0	0.0	0.0	12.3	7.9	6.3	0.0	0.0	0.0
Totals	34.0	73.8	100.0	114.0	233.8	100.0	79.8	125.0	100.0	129.5	280.8	100.0

Table 11. Overnight catch (No. and lb round weight) of fish species per gang of 50-yard gillnets in Playgreen and Kiskittogisu Lakes, July-October 1971. Data are from Manitoba Hydro Survey (Ayles MS 1973). For details of gillnet specifications, see Table 1. Values in brackets are estimated on basis of average size in adjoining Areas.

Lake	Playgreen								
Area	1		2		3		Total[a]		
No. sets	38		6		19		57		
	No.	lb	No.	lb	No.	lb	No.	lb	% wt.
Whitefish	66.5	138.8	38.2	(70.8)	33.9	54.9	55.6	110.8	44.0
Walleye	13.4	18.3	23.7	(30.9)	35.0	43.5	20.6	26.7	10.6
Sauger	1.8	0.3	5.7	(0.9)	0.3	(0.1)	1.3	0.2	0.1
Cisco	18.3	18.9	8.7	(10.0)	27.7	35.3	21.4	24.4	9.7
Burbot	1.2	1.5	1.0	(1.5)	0.3	0.5	0.9	1.2	0.5
Pike	28.6	74.3	20.3	(46.3)	17.5	34.4	24.9	61.0	24.2
Perch	8.4	3.7	3.4	(1.7)	3.1	1.7	6.6	3.0	1.2
White sucker	9.5	20.6	17.6	(45.7)	8.2	24.8	9.1	22.0	8.7
Longnose sucker	0.3	0.9	3.2	(9.5)	1.8	5.3	0.8	2.4	1.0
Totals	148.0	277.3	121.8	217.3	127.8	200.5	141.2	251.7	

[a] From Areas 1 and 3 only.

Lake	Kiskittogisu						
Area	4		5		Total		
No. sets	20		14		34		
	No.	lb	No.	lb	No.	lb	% wt
Whitefish	8.6	10.1	3.6	5.9	6.5	8.4	6.3
Walleye	19.3	24.1	53.3	72.3	33.3	43.9	32.7
Sauger	1.1	0.6	0.1	(0.1)	0.7	0.6	0.4
Cisco	8.3	2.8	8.8	1.6	8.5	2.3	1.7
Burbot	0.8	1.1	2.0	5.4	1.3	2.9	2.2
Pike	14.6	29.8	16.1	26.7	15.2	28.5	21.2
Perch	1.9	0.8	2.1	0.6	2.0	0.7	0.5
White sucker	13.3	33.3	27.4	62.5	19.1	45.3	33.8
Longnose sucker	0.7	1.6	0.1	(0.2)	0.5	1.6	1.2
Totals	68.6	104.2	113.5	175.3	87.1	134.2	

an attempt was made to integrate the various data to arrive at a consistent basis for comparing the standing stocks in the four lakes. The catch per unit effort of fish (all species) in Playgreen Lake was arbitrarily set at 100, and catches in the other lakes were related accordingly. The results are given in Table 12.

It would appear that Cross Lake supports a similar or slightly greater fish standing crop than Kiskittogisu, and that the Kiskitto Lake standing stock is only about half as large. According to the Provincial Government data (Table 10), Kiskittogisu Lake has a fish standing stock about three times greater than Playgreen. However the Manitoba Hydro data (Ayles MS 1973) indicate almost the reverse proportion (Table 11). The latter interpretation (more fish in Playgreen) is the more consistent with other indications of productivity and is the one adopted here, although necessarily with considerable reservation.

Five species - whitefish, walleye, pike, cisco, and white sucker - consistently made up over 80% of the experimental gillnet catch in all lakes in all sampling programs. Whitefish were the dominant species in Playgreen, white suckers and walleye in Kiskittogisu-Kiskitto, and all five species dominated in Cross Lake.

Rawson (1960), using roughly comparable gear to that on which the values in Table 10 are based, caught from 114 to 256 pounds of fish per set in five lakes on the Churchill River in Saskatchewan. The species composition was very similar to that in the Outlet Lakes, except that ciscoes made a bigger contribution to Rawson's catches. This may be attributed to the fact that his gillnet gangs incorporated smaller mesh sizes. On this basis, Playgreen Lake would emerge as slightly more productive of fish and Kiskittogisu and Cross Lakes about equally as

Table 12. Relative ranking of fish population standing crop in four of the Lake Winnipeg Outlet Lakes. Values are arbitrary units of weight on the basis of Playgreen Lake = 100. Ranking prepared from gillnet analyses (Ayles MS 1973; Schlick and Doan personal communications).

	Playgreen	Kiskittogisu	Kiskitto	Cross
Whitefish	39	6	3	10
Walleye	12	12	8	17
Pike	19	7	2	13
Goldeye	0	0	2	0
Cisco	5	1	+	16
White sucker	15	25	10	6
Longnose sucker	7	+	0	0
Others	3	2	2	2
	100	53	27	64

productive, as the best Churchill-River lakes; and Kiskitto about equally as productive as the poorest Churchill-River lakes.

The distribution of fishes within and among these lakes is instructive as to some of the factors controlling fish production. Whitefish are clearly favored by conditions in Playgreen Lake compared with Kiskittogisu and Kiskitto, with some improvement farther down in Cross Lake. Ayles (MS 1973) found that whitefish decreased progressively in abundance from Area 1 through Area 5 of Playgreen-Kiskittogisu Lakes (Table 11), and this was paralleled by a similar reduction in whitefish size (Figure 9). Undoubtedly contributing is the parallel tendency in bottom fauna standing crop (Table 8), and perhaps also in the distribution of reproductive habitat.

Walleye production seems relatively uniform among the lakes as a group, although in the Playgreen-Kiskittogisu section the best catches were made in the main basin of Kiskittogisu Lake (Table 11). Evidence is presented below that this may reflect the distribution of walleye spawning opportunities.

Pike abundance parallels that of whitefish, both among the lakes as a group, and within the more thoroughly studied Playgreen-Kiskittogisu basins. In the latter two lakes the mean and modal size of pike is greatest in Area 1 (Figure 10). No explanation is apparent and it can only be inferred that forage fish production is better here. No pike food or feeding data are available.

Goldeye are encountered only in the lower lakes (Kiskitto, Pipestone, Drunken, Cross). Carp and quillback sucker were found only in Kiskitto, which is probably the shallowest, most turbid lake in the group. Sturgeon are apparently confined mainly to the two largest lakes,

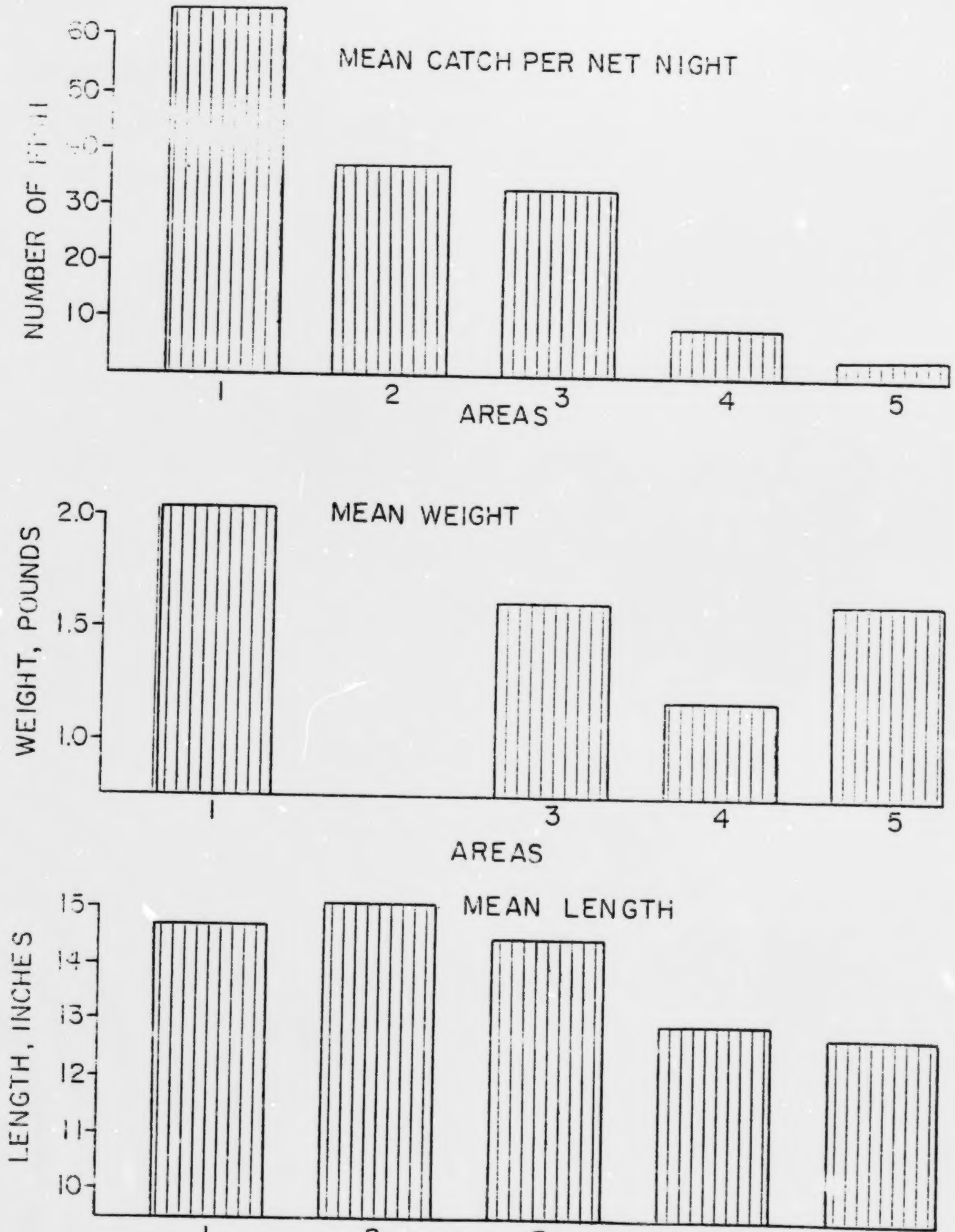


Figure 9 . Catch per unit effort and mean size of whitefish taken by experimental gillnets in 5 areas of Playgreen-Kiskittogisu Lakes, 1971.

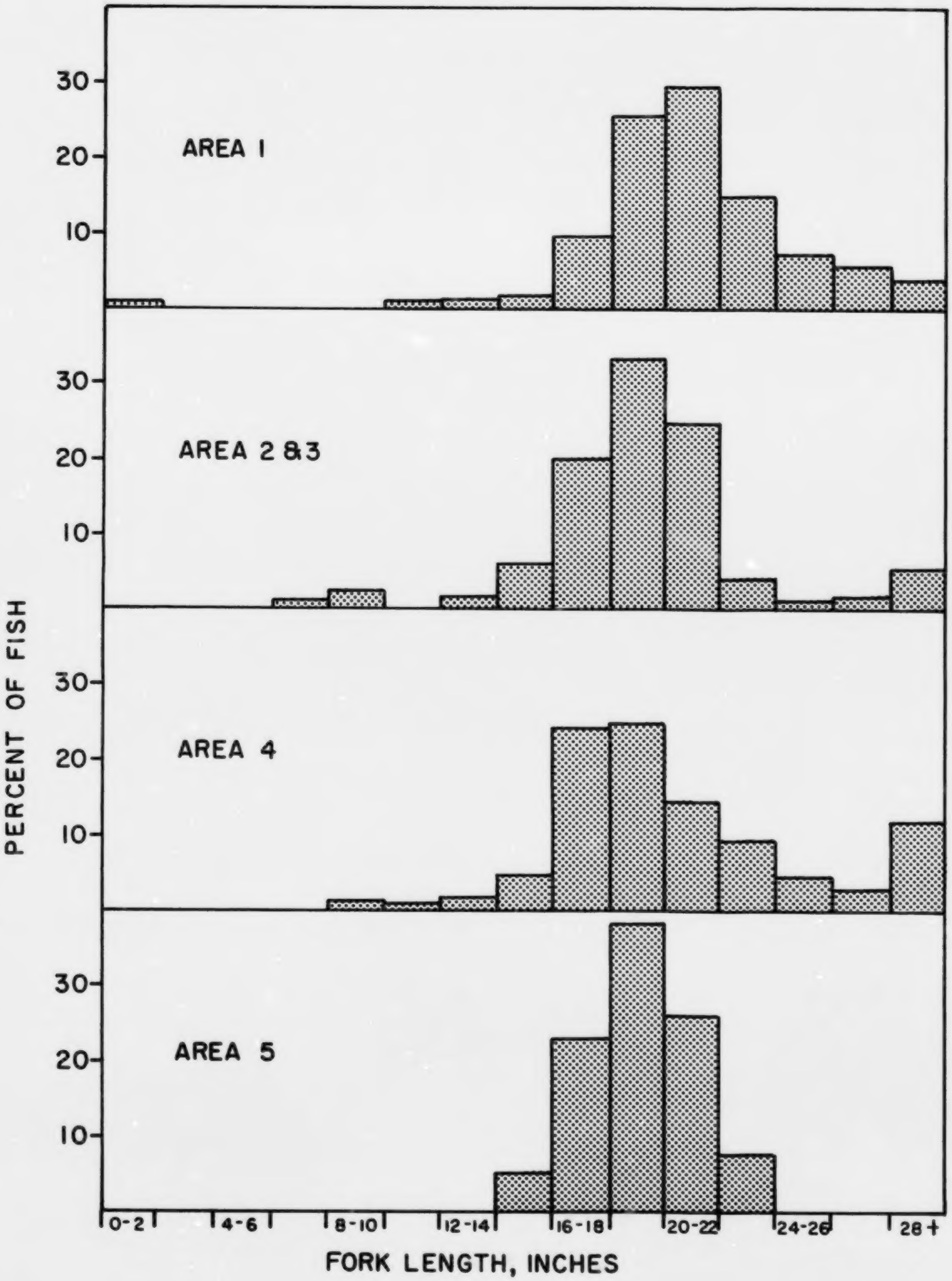


Figure 10. Length-frequency composition of northern pike in 5 regions of Playgreen and Kiskittogisu Lakes, 1970-71. Data from Manitoba Hydro Study (Ayles MS 1973).

Playgreen and Cross. Sauger are most numerous in Playgreen Lake, a particularly in Area 2 (Ayles MS 1973). This is consistent with th general preference for flowing-water habitat.

6.5.3. Fish growth:

Growth of whitefish, walleye, and pike in the Lake Winnipeg Ou Lakes area was analysed from scale readings provided by the Manitob Department Mines, Resources and Environmental Management (personal munications W. Musker, R. Schlick, K. H. Doan, W. Pollard). These data were from surveys conducted at the following times:

a) Cross Lake: June 1965.
b) Playgreen Lake: August 1971.
c) Lake Winnipeg (Mossy Point): July 1971.
d) Kiskitto Lake: June 1972.
e) Kiskittogisu Lake: July 1972.

A composite tabulation of mean lengths-at-age was prepared fr data (Table 13). It will be noted that growth rates for particula species are generally of similar form. However subtle differences exist, as outlined below. Analysis of covariance was employed to differences between the slopes of the regressions of fork length o (growth rate), and between the sample mean lengths adjusted to a c age (elevation). Differences between sample mean ages were tested analysis of variance. These tests were confined to adjoining lake i.e. Playgreen-Lake Winnipeg, Playgreen-Kiskittogisu, and Kiskitto Kiskitto. The results are summarized in Table 14.

With regard to whitefish growth, the higher elevation of the age regression line for the north basin of Lake Winnipeg suggests growth in Playgreen Lake during the first year or two of life. Th could be a valid interpretation; unfortunately the ageing of this

Table 13. Comparative length-at-age of three fish species in the Lake Winnipeg Outlet Lakes. Values are fork length (inches) at age years (annuli). Data from Manitoba Department Mines Resources, Environmental Management.

Whitefish	1	2	3	4	5	6	7	8	9	10	Sample period
Lake Winnipeg[a]	-	-	13.04	15.38	15.99	18.10	-	-	-	-	July 1971
Playgreen	-	10.10	11.47	14.15	15.59	16.42	17.32	-	-	-	August 1971
Kiskittogisu	-	10.40	11.83	13.51	15.23	16.20	17.16	18.43	18.05	-	July 1972
Kiskitto	-	10.50	10.86	13.70	14.68	16.07	17.22	17.74	18.20	-	June 1972
Cross	-	9.00	11.90	13.00	16.08	16.25	18.07	19.78	21.21	21.80	June-July 1965
Walleye	1	2	3	4	5	6	7	8	9	10	
Playgreen	-	12.26	13.30	14.70	16.02	18.10	17.50	21.00	-	-	August 1971
Kiskittogisu	-	-	13.15	14.98	16.26	17.80	18.90	-	-	-	July 1972
Kiskitto	-	11.47	12.48	13.88	15.27	16.51	19.30	17.50	-	-	June 1972
Cross	-	-	13.10	13.20	16.04	17.52	18.57	18.97	21.40	21.20	June-July 1965
Pike	1	2	3	4	5	6	7	8	9	10	
Playgreen	9.50	-	16.72	18.44	20.41	22.49	24.20	25.70	26.30	-	August 1971
Kiskittogisu	-	-	16.32	18.13	20.40	22.65	26.60	28.22	29.70	-	July 1972

[a] Mossy Point.

particular pair of samples was done by different individuals, so that it is impossible to make a definitive interpretation. In any event, the slope of the length-age regression is greater for whitefish in Playgreen Lake indicating that they grow faster at the later ages. Whitefish in Playgreen Lake as a whole grow significantly faster than in Kiskittogisu at all ages (both the slope and the elevation of the Playgreen regression line are higher). Whitefish in Kiskittogisu gr faster than in Kiskitto at the earliest ages, but not later. Whitef in Cross Lake appear to grow faster than in any of the other lakes (Table 13); however no statistical tests were performed. The result do indicate the general superiority of Playgreen Lake (and perhaps o Cross Lake) as whitefish habitat compared to Kiskitto and Kiskittogi this confirms some assumptions made earlier.

Five-year-old whitefish dominated the Manitoba Hydro catches (A MS 1973) in all Areas of Playgreen-Kiskittogisu (Figure 11), and a strong group of 3-year-olds was also appearing. The dominant age-cl averaged about one inch longer in the Playgreen samples than in thos from Kiskittogisu. Whitefish growth in the Outlet Lakes is generall faster than that summarized by Carlander (1969) for lakes in northe and western Canada (Ayles MS 1973).

Young walleyes were found to grow faster in Kiskittogisu than either Playgreen or Kiskitto Lakes, but there was no difference in slope of the regression (growth rate) among the older fish. Pike g faster in Kiskittogisu than in Playgreen (later ages) although the difference is very small.

Table 14. Summary of statistical comparisons of age and growth characteristics for three fish species in adjoining lakes of the Lake Winnipeg Outlet area. Where differences between pairs of lakes were found to be significant, the name of the lake with the higher value is given in the appropriate box. If no significant difference was found, the notation "NSD" is given. See text for dates and other details.

A. Whitefish

	Playgreen			Kiskittogisu		
	Slope	Elevation[a]	Mean Age	Slope	Elevation[a]	Mean Age
Lk. Winnipeg	Playgreen	Lk. Winnipeg	Playgreen	-	-	-
Playgreen	-	-	-	Playgreen	Playgreen	NSD
Kiskitto	-	-	-	NSD	Kiskittogisu	Kiskitto

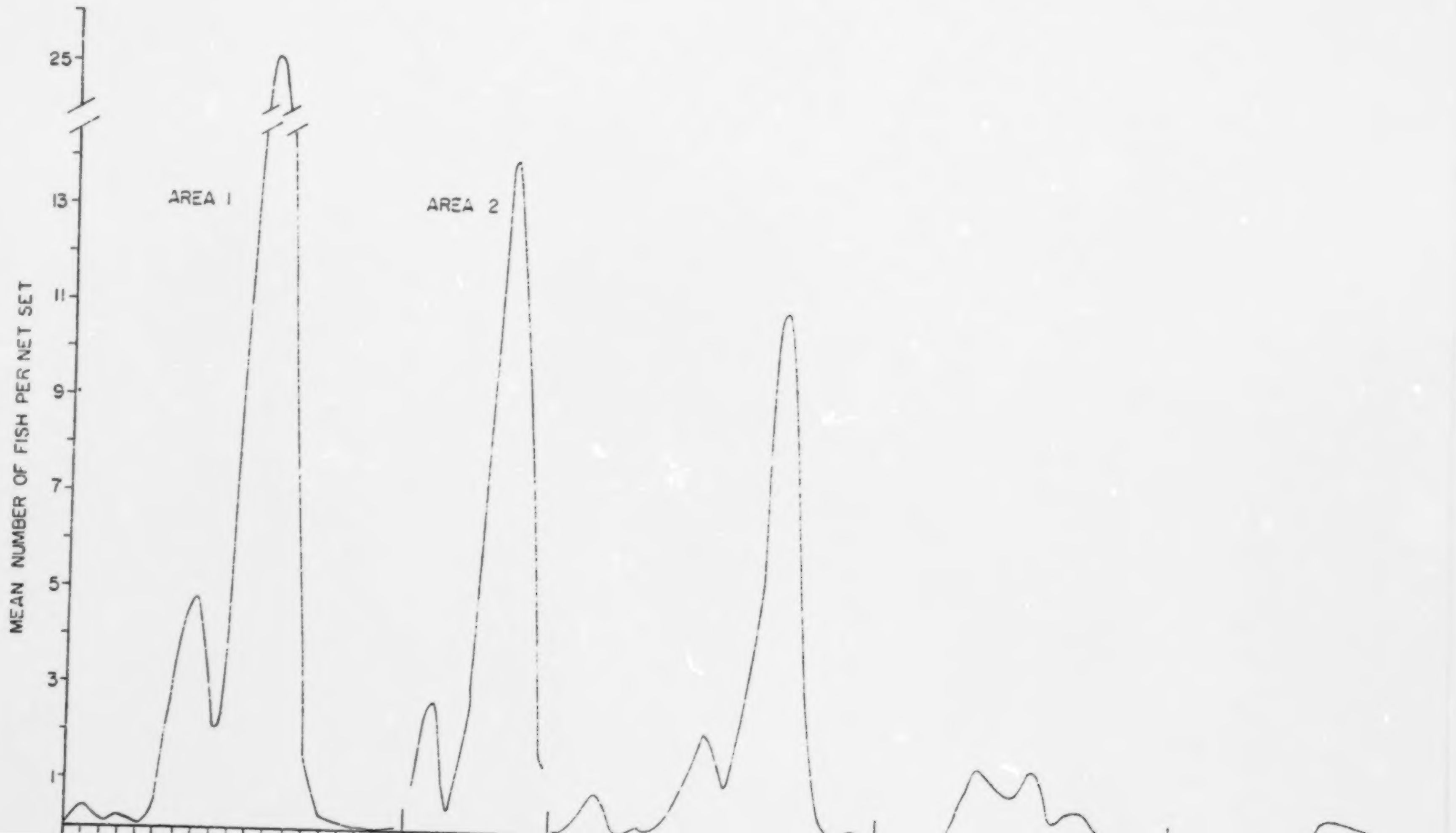
B. Walleye

	Kiskittogisu		
	Slope	Elevation[a]	Mean Age
Playgreen	NSD	Kiskittogisu	Kiskittogisu
Kiskitto	NSD	Kiskittogisu	Kiskittogisu

C. Northern pike

	Kiskittogisu		
	Slope	Elevation[a]	Mean Age
Playgreen	Kiskittogisu	NSD	Kiskittogisu

[a] Tested on the basis of mean lengths adjusted to a common age.


25
13
11
9
7
5
3
1
MEAN NUMBER OF FISH PER NET SET
AREA 1
AREA 2

6.5.4. Fish condition:

The same sample pairs which were analysed for growth (Section 6.5.3) were also tested for comparative condition. Differences between the slopes of the regressions of log weight on log length, and between the sample mean weights adjusted to a common length (elevation) were tested by analysis of covariance; and differences between the sample mean lengths were tested by analysis of variance (Table 15).

According to the elevation of regression lines (mean weights adjusted to a common length), Playgreen Lake whitefish are plumper and also average somewhat larger than those in Kiskittogisu or Lake Winnipeg. According to Ayles (MS 1973), whitefish condition is best in the south end of Playgreen Lake. The length-weight regressions for Kiskittogisu-Kiskitto Lakes, however, are indistinguishable. The general pattern of whitefish condition closely parallels the actual abundance of whitefish, and also the abundance of bottom fauna.

Walleyes are significantly plumper in Playgreen than in Kiskittogisu, but display equivalent condition for Kiskittogisu-Kiskitto (Table 15). However the largest walleyes occur in Kiskittogisu Lake, particularly in the south end. Ayles (loc. cit.) found that, within Playgreen Lake, walleyes were plumpest in Areas 1 and 2. Again, there is a good parallel here between fish condition and basic productivity.

Northern pike are plumper in Playgreen than in Kiskittogisu, but the latter tend to "catch up" at the larger sizes (Table 15). Pike in southern Playgreen are heavier per unit length than in northern Playgreen or Kiskittogisu. This coincides with a larger pike population in South Playgreen Lake (Table 11).

Table 15. Summary of statistical comparisons of average size, and of length-weight characteristics, for three fish species in adjoining lakes of the Lake Winnipeg Outlet area. Where differences between pairs of lakes were found to be significant, the name of the lake with the higher value is given in the appropriate box. If no significant difference was found, the notation "NSD" is given. See text for dates and other details.

A. Whitefish

	Playgreen			Kiskittogisu		
	Slope	Elevation[a]	Mean length	Slope	Elevation[a]	Mean length
Lk. Winnipeg	NSD	Playgreen	Playgreen	-	-	-
Playgreen	-	-	-	NSD	Playgreen	Playgreen
Kiskitto	-	-	-	NSD	NSD	Kiskitto

B. Walleye

	Kiskittogisu		
	Slope	Elevation[a]	Mean length
Playgreen	NSD	Playgreen	Kiskittogisu
Kiskitto	NSD	NSD	Kiskittogisu

C. Northern pike

	Kiskittogisu		
	Slope	Elevation[a]	Mean length
Playgreen	Kiskittogisu	Playgreen	NSD

[a] Tested on the basis of mean weights adjusted to a common length.

6.5.5. Fish reproduction:

The general spawning periods, preferred spawning site characteristics, and young-of-the-year ecological requirements for the fish species endemic to the Outlet Lakes are summarized in Table 16. This tabulation was prepared mainly from published accounts from other locations since little is known about the reproductive habits of fishes in the Outlet Lakes per se. A few inferences were drawn from the distributional and other data presented above, and from interviews with local residents.

It is immediately apparent that there is very little positive correlation between the distribution of "preferred" shoreline categories as outlined in an earlier section, and the abundance of the particular fish species supposedly favored by those shoreline types. South Playgreen Lake, with the best whitefish population, apparently has the least favorable shorelines (Table 4). However this could indicate reproduction of whitefish in adjoining Little Playgreen Lake, where preferred shorelines are abundant. The shoreline-fish population relation for walleyes is even less positive. Walleyes probably spawn extensively in small tributaries where such occur, thereby avoiding the prevalent adverse in-lake effects of high turbidity and exposed, wind-swept shores. The distribution, and more particularly the commercial harvest of walleyes (Appendix B) tends to support this point of view. The best commercial walleye harvests (per unit area) are made in Drunken Lake, and it is likely that the Minago River and/or Black Duck Creek provide the reproductive basis. The distribution of walleyes as indicated by gill-net catches in June and July (just after the spawning season) in Kiskittogisu and Kiskitto Lakes (Figure 12) suggests a positive

Table 16. Summary of reproductive habits and early life history requirements of fish species found in the Lake Winnipeg Outlet Lakes.

Species	Spawning period	Spawning area		Rearing of young-of-the-year	
		Depth	Substrate	Habitat	Food
Whitefish	Late Oct.-early Nov.	Generally 4-10 ft	Generally clean, rocky reefs. Sometimes gravel, sand	Rocky shores, moving to midwater in summer	Zooplankton
Cisco	Freeze-up	Generally 4-15 ft	Clean rocky or gravel reefs	Shallow protected bays, moving to midwater	Zooplankton
Burbot	Mid-winter	Variable	Streams; sandy or gravel shoals	Variable	Bottom fauna
Pike	Late April-May	Generally less than 2 ft	Variable, but generally with old or submerged vegetation	Inshore, among debris and vegetation	Zooplankton → bottom fauna → fish
Suckers	May	Very shallow	Riffles of streams, also lake shores	Inshore in quiet water	Plankton → benthos
Walleye	May -early June	Shallow	Variable. Generally clean pools and riffles; also clean rocky reefs and shores	Mainly stream-mouths, later to midwater	Zooplankton → bottom fauna and fish
Sauger	June	3-10 ft	Mud or sand	Shallow, sheltered, generally turbid areas	Zooplankton → bottom fauna and fish
Goldeye	June	Shallow	Gravel shoals or quiet expanses of rivers and tributaries; perhaps also marshy lakes	Surface at first; then prefer marshy backwaters	Zooplankton, insects
Sturgeon	June	2-10 ft	Generally in turbulent water over hard bottom. Perhaps also on wind-swept shores	Shallow bays and eddies	Minute crustaceans
Forage fishes	May - July	Shallow	Variable	Generally inshore	Plankton, algae, bottom fauna

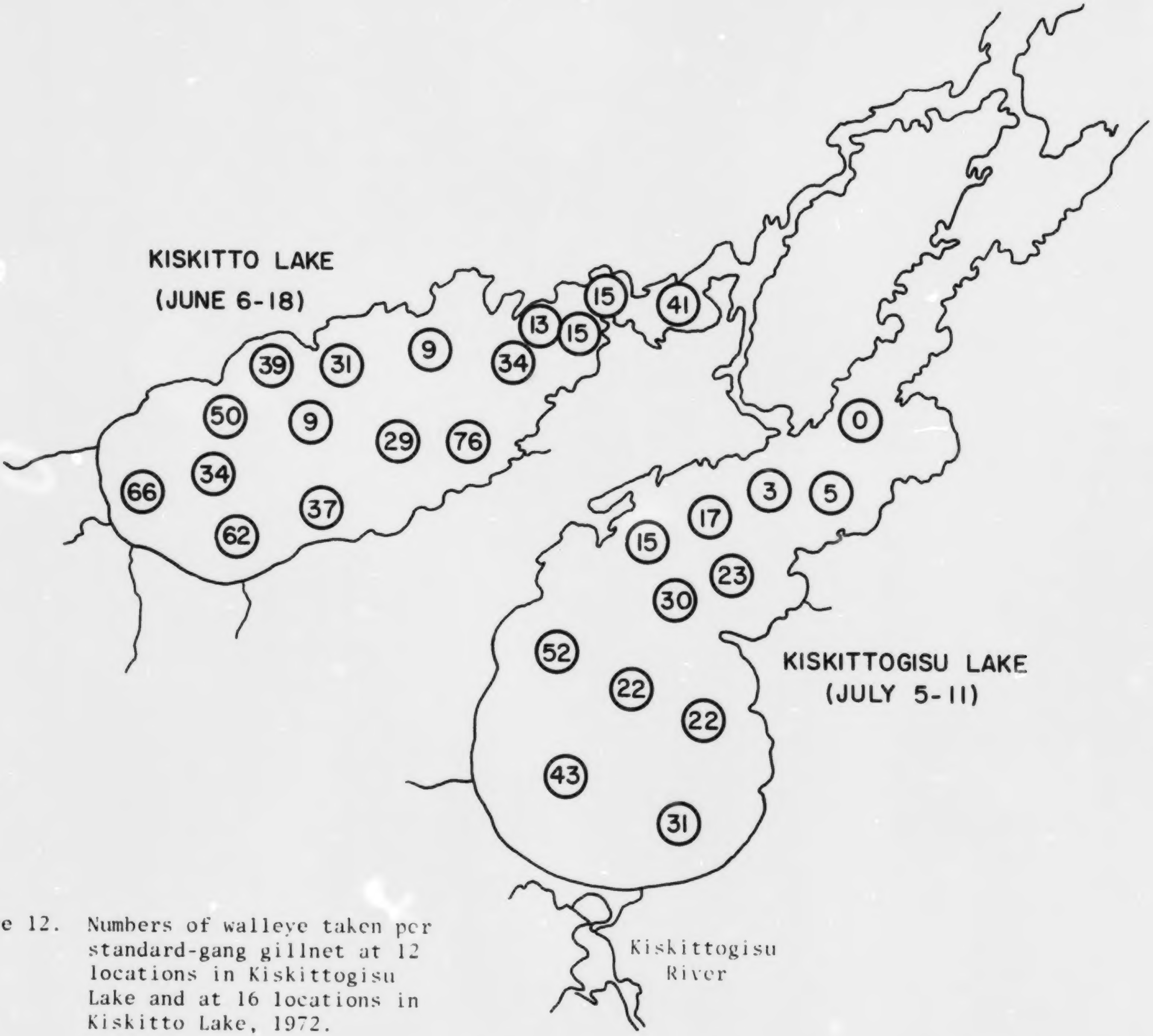

KISKITTO LAKE
(JUNE 6-18)
15
41
13
15
39
31
9
34
50
9
29
76
66
34
37
62
0
3
5
17
15
23
30
52
22
22
43
31
KISKITTOGISU LAKE
(JULY 5-11)
Kiskittogisu River

Figure 12. Numbers of walleye taken per standard-gang gillnet at 12 locations in Kiskittogisu Lake and at 16 locations in Kiskitto Lake, 1972.

association with the tributary streams. That walleyes do in fact extensively utilize Kiskittogisu River and its associated lagoons and tributaries for spawning is borne out by the observations of local residents (see letter from Conservation Officer D. Allen: Appendix C). The extent of walleye spawning, if any, in the channels of the Nelson River itself is unknown, but could be significant.

South Playgreen Lake has the best pike population in the area, and it also has the most favorable shoreline distribution for this species (Table 4). However there is no clear relationship among the other lakes. As with walleye, it seems likely that pike rely heavily on the small tributary streams for spawning.

The spawning grounds of sturgeon are of some interest, if only because of the high unit value and low abundance of this species. According to Sunde (personal communication) sturgeon in the Churchill and Nelson River systems tend to ascend the rivers or tributaries to the first insurmountable obstruction, and then to spawn (in June) in such locations. This type of spawning is effectively precluded in Playgreen Lake and according to Nelson Scribe (long-time resident of the area), the sturgeon spawn in shallow water (about 2 feet) in a relatively restricted area on the west shore of Playgreen Lake opposite the entrance to the East Channel.

Spawning of whitefish in the Outlet Lakes has been and remains a matter of considerable interest and concern. The situation is complicated by the reasonably well-documented spawning of whitefish from Lake Winnipeg in Playgreen Lake. Movement of whitefish from Lake Winnipeg into Playgreen was first demonstrated in a tagging study by Kennedy (1954); it has been the object of more recent investigations by the

Manitoba Government. The phenomenon is demonstrated by the seasonal catch-per-unit effort data for Playgreen and Kiskittogisu Lakes as reported by Ayles (see Figure 13). According to Pollard (personal communication) several whitefish tagged in Lake Winnipeg near Warren Landing were captured, during the same autumn, in the channels of the Nelson River near Norway House. This suggests that these fish travelled to that area to spawn, since they were captured during the spawning period. Unfortunately, there was no concurrent fishing effort in other parts of Playgreen Lake so it could not be determined if the fish moved to other areas as well. None of the ±3800 tags applied at Warren Landing were recovered in Playgreen Lake during the ensuing summer commercial fishery; this suggests that the fish return to Lake Winnipeg after spawning. Recovery of whitefish tagged at Warren Landing by the commercial fishery throughout the north basin of Lake Winnipeg (north of Long Point) implies that those fish congregating at Warren Landing in the spawning season have a major impact on the Lake Winnipeg fishery. The possibility that significant numbers of these fish actually migrate into Playgreen Lake to spawn is thus an important dimension to be considered.

6.5.6. Fish movement and interchange:

The phenomenon of whitefish interchange between Lake Winnipeg and Playgreen was outlined in the previous section. What is intended here is to summarize the background information indicating movement, or lack of movement, of the major fish species among the Outlet Lakes.

The data on growth and condition presented earlier suggest that:

a) The whitefish population of Playgreen Lake is distinct from the other lakes. There is a significant influx of whitefish from

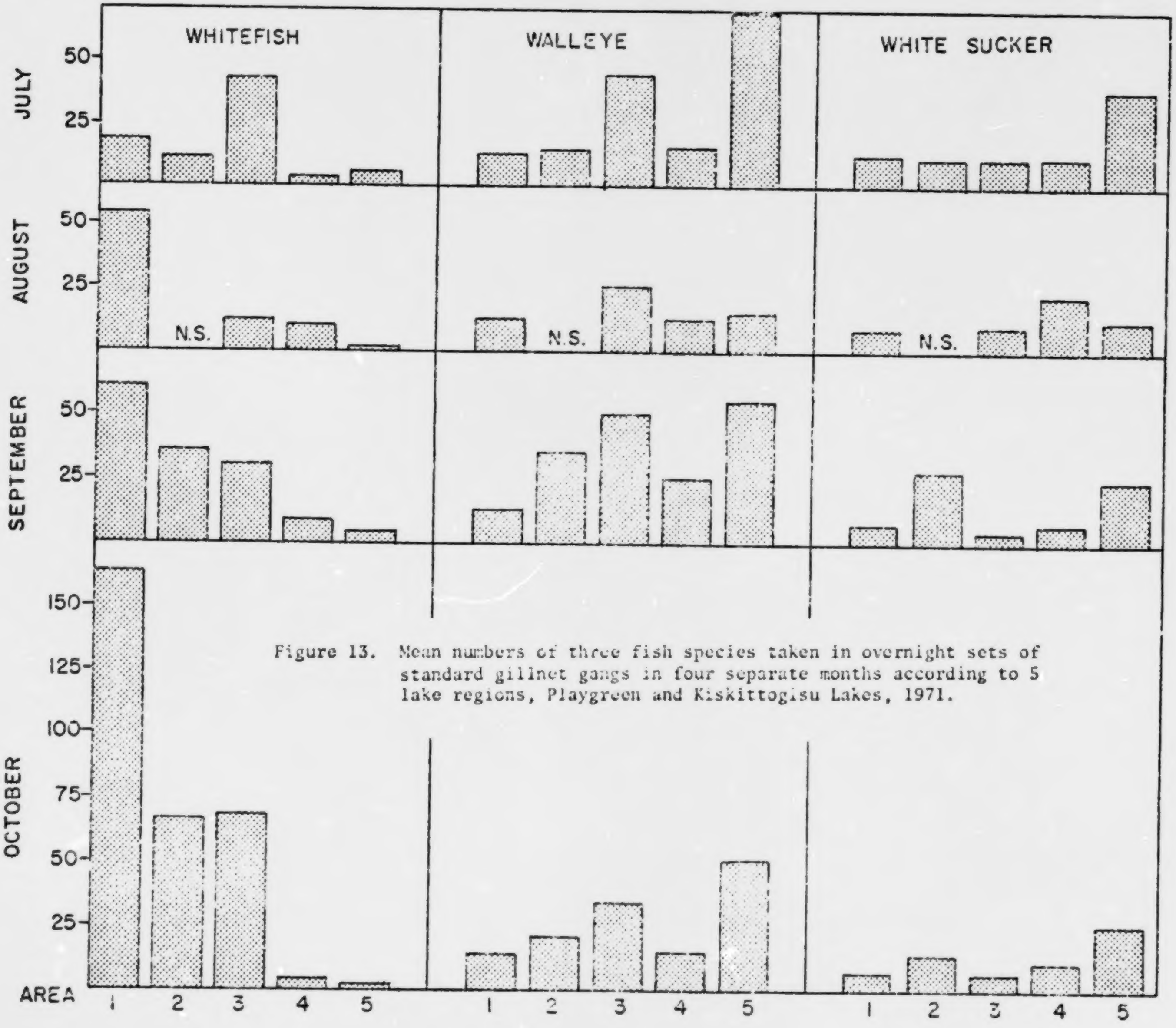


Figure 13. Mean numbers of three fish species taken in overnight sets of standard gillnet gangs in four separate months according to 5 lake regions, Playgreen and Kiskittogisu Lakes, 1971.

Lake Winnipeg into Playgreen Lake during the spawning season, but the Playgreen Lake commercial whitefish fishery appears to be based on indigenous Playgreen stocks. This inference is supported for whitefish, and for other species as well, by the general lack of correlation between the seasonal commercial fish catch composition in the Playgreen and Lake Winnipeg fisheries (Figure 14).

b) The walleye and pike populations of Playgreen Lake do not mix extensively with the lower lakes.

c) Whitefish and walleye may interchange to a considerable extent between Kiskittogisu and Kiskitto Lakes.

The extent or significance, if any, of fish migrations up and down the main channels of the Nelson River for reproduction or other purposes is entirely unknown. It seems intuitively unlikely that this could be an important consideration, except perhaps in localized river sections. It is probable that walleye, pike, sturgeon, suckers, goldeye and perhaps whitefish ascend part way up the Nelson River channels from Cross and Pipestone Lakes, but unlikely that they traverse the complete sections in significant numbers. Downstreaming of larval and juvenile fishes may be of importance in some situations; e.g. whitefish hatched in Little Playgreen could possibly contribute to the whitefish population in Pipestone and Cross Lakes even though not originating from those stocks. Koshinsky (MS 1968) concluded that whitefish stocks in certain Shield lakes without reproductive opportunities were maintained by recruitment with fry washed down from lakes above.

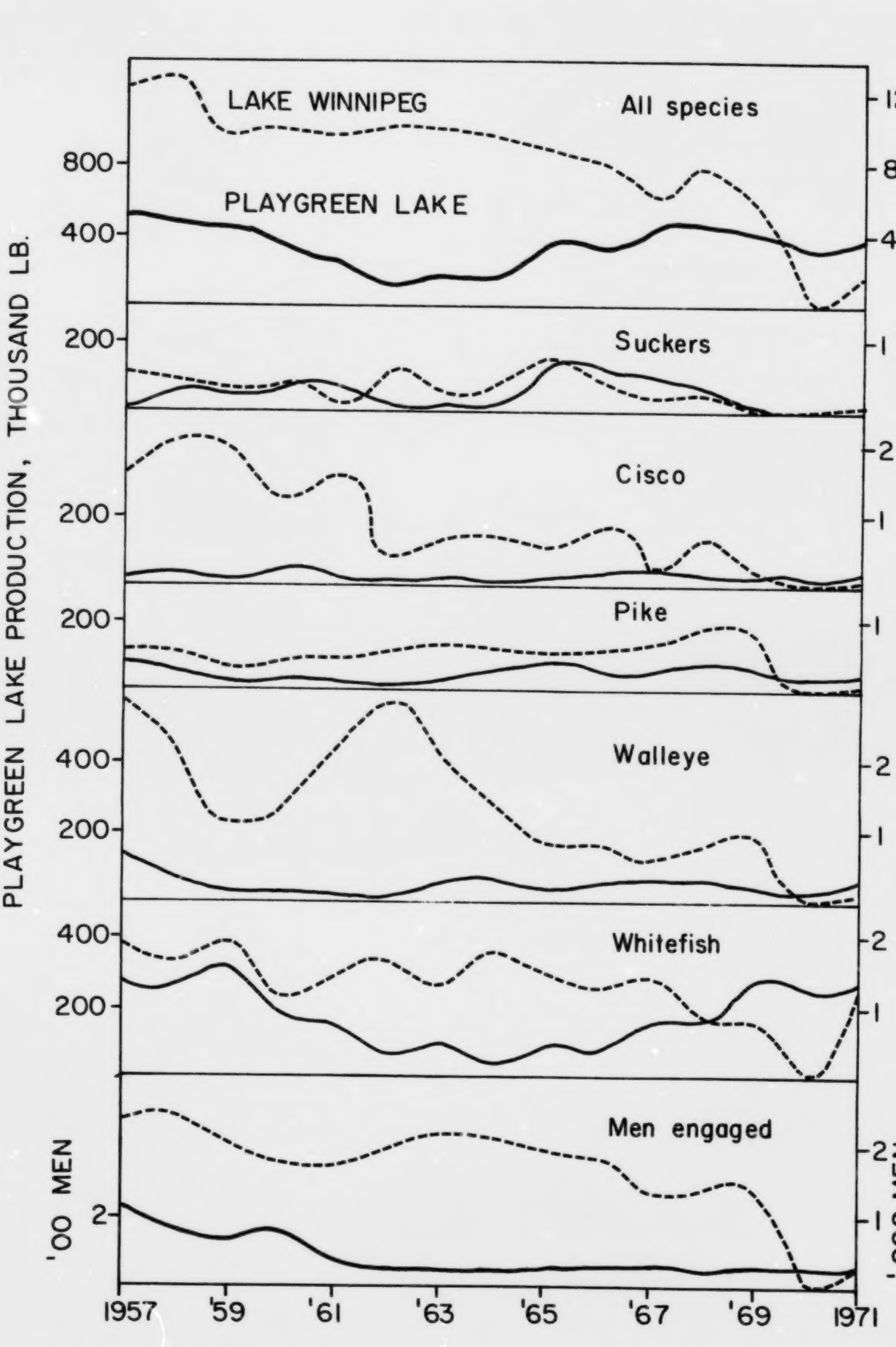


Figure 14. Comparative participation and catch volume - composition for Playgreen Lake and Lake Winnipeg commercial fisheries, 1957-1 Only those species which have contributed significantly to th Playgreen Lake fishery are plotted individually.

6.6. Current fishery exploitation:

6.6.1. Sport fishery:

There is no concerted sport-fishery in the Outlet Lakes area at present (Weagle MS 1973). There are no facilities catering to such activity, very few recreationists come to the area, and the local residents have little inclination for sport fishing. Interviews with staff of Manitoba Hydro and the dredging contractor at the 8-mile channel site produced entirely negative results as to sport fishing activity, and it is a safe assumption that such a fishery is virtually non-existent at present.

The potential of these lakes to support sport-fishing is impossible to gauge accurately with the data at hand. Generally in areas this remote, in this general situation, a sport fishery must meet one or more of the following criteria to attract significant participation:

a) Provide lake trout with good catch per unit effort and/or trophy sizes.

b) Provide northern pike at trophy sizes.

c) Provide walleye with exceptional catch per unit effort.

d) Provide good alternate activity options.

The first criterion cannot be met because lake trout do not inhabit these waters. The second criterion is generally very difficult to meet, or at least to sustain, in morphometrically uniform Canadian Shield lakes with continuous and active commercial or domestic gillnet fisheries (Koshinsky MS 1972). However there does seem to be some potential in this regard judging by the size frequency distribution of pike taken in the Manitoba Hydro gillnetting program (Figure 10). Pike weighing 6 - 8 lb and larger are not uncommon, particularly in the Kiskittogisu channel

(Area 4). Appropriate walleye stocks would seem to exist to meet the third criterion, particularly in such special situations as Drunken Lake (Figure 1). However mere presence of walleyes does not always g antee angling success, and considerable in-the-field assessment would required before any conclusions could be reached. The fourth criteri that of alternative activity options, has generally not been availabl (according to ordinary definition) up to the present time. However t construction and subsequent operation of the Manitoba Hydro facilitie in this area will tend to provide such options, and the new and impro access opportunities will tend to ameliorate all the negative constra cited above. These aspects are evaluated in more detail below. Anot potential redeeming feature for development of sport-fishing potentia the area is the availability of species, other than those referred to above, which are amenable to angling. These include sauger, yellow p goldeye, whitefish, and sturgeon. However none of these species are ticularly unique to this area nor are they of particularly great abun or size. Given present general angling preferences and techniques, i unlikely that such species will exert much influence on sport fishery velopment in this region.

6.6.2. Domestic fishery:

Weagle (MS 1973), on the basis of interviews conducted in late 1 estimated that domestic fish consumption by residents of the area ave about 150 lb per family per year. This suggests an annual domestic h vest of about 105,000 lb by the residents of Norway House, and 75,000 by the residents of Cross Lake community. The latter would take thei domestic harvest from Cross Lake itself, whereas most of the domestic harvest at Norway House is taken from Little Playgreen Lake and the adjoining Nelson River channels, and is heavily dependent on spawning run whitefish. It is unlikely that domestic fishing (except as an adjunct of commercial fishing) is conducted on any of the other Outle Lakes since they have no permanent communities.

It might be noted that Schlick (personal communication) estimate the Norway House domestic fishery, on the basis of studies at Island Lake in Eastern Manitoba, to be nearer 250,000 lb annually. Mr. Nels Scribe, former Chief at Norway House, suggests (personal communicatio that domestic fish consumption averages about 130 lb per person per year, and 900 lb per sled dog. On this basis, annual consumption wou be about 410,000 lb at Norway House, and 280,000 lb at Cross Lake. C sumption is presumably declining as a consequence of replacement of s dogs by power toboggans, but the human consumption appears to be the dominant element in any event.

6.6.3. Commercial fishery:

With the exception of Little Playgreen Lake, the Lake Winnipeg Ou Lakes are all subjected to commercial gillnet fisheries. The history regulations governing these fisheries has been reviewed by Weagle (MS and a summary of present regulations (1971-72) is given in Table 17. total gazetted limit listed for these eight lakes is 560,000 lb. Exc for Playgreen Lake, which is fished primarily by residents from Norway House, preference in licencing for the other Outlet Lakes is given to residents of Cross Lake.

These are primarily summer fisheries. Total recent fish landings and values for the Outlet Lakes, and their contribution to the total Manitoba fishery (%), have been as follows:

Table 17. Summary of current regulations, and of participation, deliveries, and values to fishermen for 1970 and 1971 for the Lake Winnipet Outlet Lakes commercial gillnet fisheries.

	Current regulations[a]				Total Participation, deliveries, and values[d]			
Lake	Quota cwt.	Species[b]	Mesh,[c] inches	Season	Season[e]	Parti-cipants	Deliveries, cwt.	Values to fishermen, $
Playgreen	2500	Wh,W,S	4.25-5.25	June 1 - Sept. 30	1970 (S) 1971 (S)	50 53	3191 3837	97,053 100,301
Playgreen[f]	50	St	13.0	June 15 - Oct. 31	-	-	-	-
Little Playgreen		No commercial fishing						
Kiskittogisu	500	Wh,W,G	4.25-5.25	June 1 - Oct. 20 and Nov. 1 - April 15	1970 (S) 1971 (S)	4 4	585 184	17,549 6,617
Kiskitto	300	Wh,W,G	4.25-5.25	June 1 - Oct. 20 and Nov. 1 - April 15	1970 (S) 1971 (W)	4 3	184 64	4,865 1,300
Pipestone	300	Wh,W,G	4.25-5.25	June 1 - Oct. 20 and Nov. 1 - April 15	1970 (S) 1971 (S)	3 5	29 41	1,052 870
Cross	1000	Wh,W,G,P	5.25	June 1 - Oct. 20, and Nov. 1 - April 15	1970 (S) 1971 (S)	11 16	1009 1010	29,479 32,866
Drunken	100	Wh,W	4.25-5.25	June 1 - Oct. 20 and Nov. 1 - April 15	1970 (S) 1971 (S)	4 2	141 132	4,623 4,656
Walker	850	Wh,W	4.25-5.25	June 1 - Oct. 20 and Nov. 1 - April 15	1970 (S) 1971 (S)	13 10	748 598	23,500 23,694

[a] From Canada Gazette Part 2: 105(12) 23 June 1971.

[b] Wh = lake whitefish, W = walleye, S = sauger, G = goldeye, P = northern pike, St = Sturgeon

[c] Maximum allowable gear per license is 1500 yards all lakes.

[d] Records of the Freshwater Fish Marketing Corporation.

[e] S = summer season; W = winter season.

[f] Gazetted for "that portion of Big Playgreen and Cross Lakes lying north of the north boundary of Township 54 to the upper end of Whitemud Falls. No separate statistics available for this fishery.

	Total landings		Total values	
	Cwt	%	'000$	%
1970 Summer	7260	8.1	179.1	14.2
1970-71 Winter	99	0.1	1.5	0.2
1971 Summer	7274	8.1	173.4	11.9
1971-72 Winter	354	0.5	7.3	0.8

The historical total and mean annual commercial fish production, fishery participation, and value to fishermen is summarized for the individual lakes in Appendix B. The Playgreen Lake fishery is by far the largest. During the past 12 years it has contributed 59% to the total mean annual Outlet Lakes catch (522,400 lb), and 58% of the total mean annual Outlet Lakes value ($104,200). These data are summarized in Table 18. It will be noted that total mean annual production over this 12-year period has averaged very near (93%) the present total gazetted limit for these lakes.

The mean annual catch composition and pounds per acre harvest for each lake over the same period (1960-1971) is summarized in Figure 15. Detailed annual catch statistics for the period of record are given by Weagle (MS 1973). Whitefish are the main contributors to the catch in Playgreen, Pipestone, Cross, and Walker Lakes; walleyes are the main contributors in Kiskittogisu, Kiskitto, and Drunken Lakes. In general, walleyes are more prominent in the catch from those lakes which are least subject to the flushing action of the Nelson River. The most diverse harvest, in terms of species composition, is made in Playgreen Lake. This may reflect a more diverse fish fauna because of interchange with Lake Winnipeg; however another factor is probably the better convenience and economics of transport (see below) which allows profitable marketing of suckers and ciscoes. Northern pike are taken in substantial quantities from all the lakes even though they are part of the

Table 18. Summary of commercial fishing participation, fish production, and values to fishermen for Lake Winnipeg Outlet Lakes, 12-year period, 1960 - 1971. Adapted from Weagle (MS 1973).

	No. of licenses		Fish production, cwt		Value to Fishermen, $ 000	
	Avg/yr.	%	Avg/yr.	%	Avg/yr.	%
Playgreen	75.0	65	3068	59	60.6	58
Kiskittogisu	2.8	2	191	4	4.2	4
Kiskitto	3.7	3	163	3	3.5	3
Pipestone	2.8	2	78	1	1.3	1
Cross	14.9	13	875	17	18.2	18
Drunken	2.3	2	93	2	2.7	3
Walker	14.8	13	756	14	13.7	13
Totals	116.3		5224		104.2	

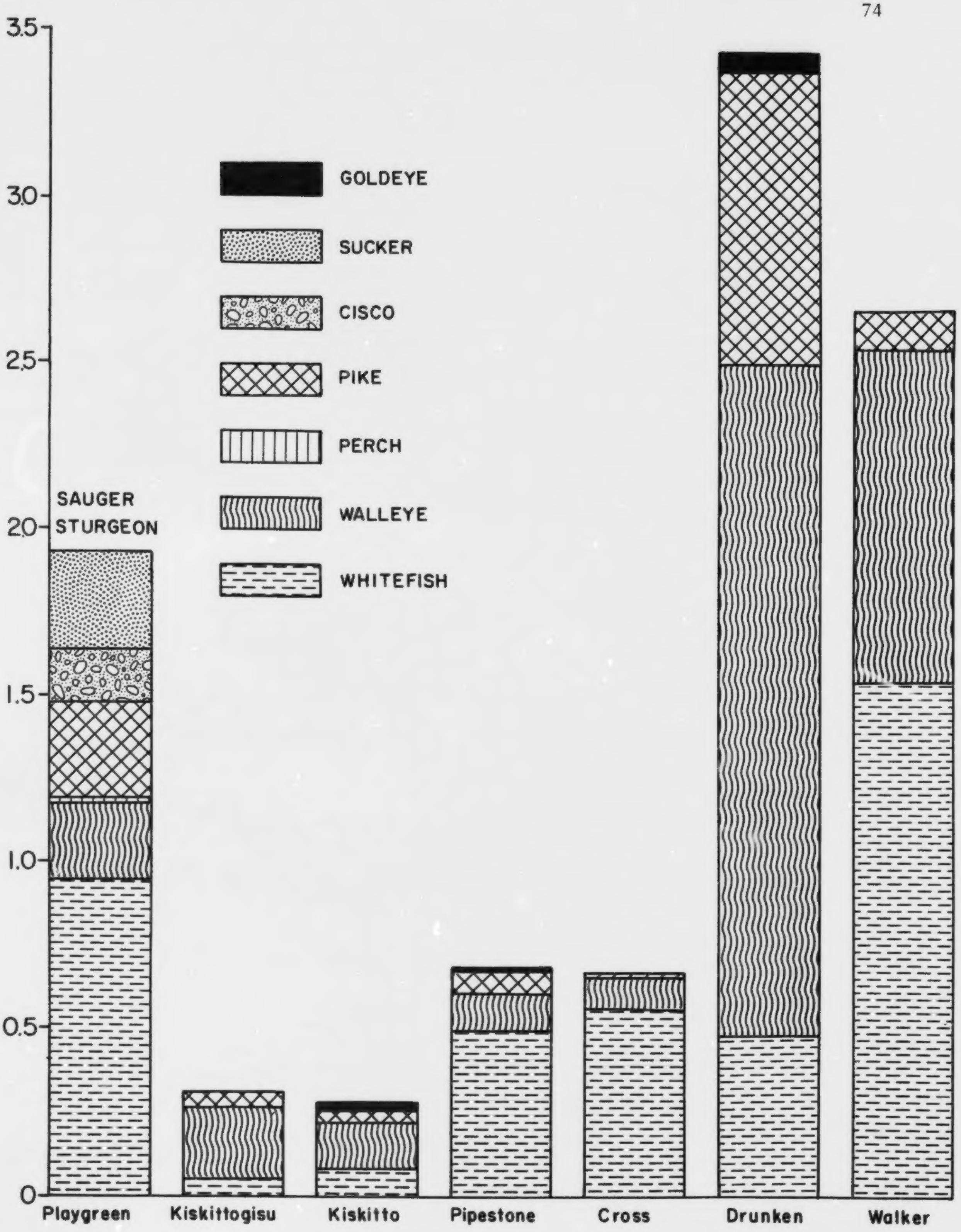


Figure 15. Mean annual commercial fish production (lb/acre) by species from seven lakes of the Upper Nelson River system, Manitoba, 1960-1971.

gazetted limit only for Cross Lake (Table 17). Goldeye contribute significantly more to the catches from Kiskitto Lake than from any of the others. Sturgeon have been recently recorded (albeit in very small quantities) only from the Playgreen fishery. The large proportion and absolute yield of "game-fish" species (walleye, pike, and goldeye) from Drunken Lake is of interest. This would appear to reflect a highly positive influence from the Minago River or Black Duck Creek on reproduction and general productivity of these species.

Production from the main producing lakes (Playgreen, Cross and Walker) has been quite consistent over about the past 7 years at least (Weagle MS 1973). Production from the other lakes has been rather more erratic; this undoubtedly is a strong reflection of the amount of effort actually expended. According to Weagle (loc. cit.), the entire season (4 months) was required to harvest the Playgreen Lake quota in 1970, 40 days (June 7 to July 17) were required in 1971, and only 27 days (with considerable inefficiencies wrought by overtaxed handling facilities) in 1972. This strongly suggests a marked increase in fish stocks in Playgreen Lake over this period. Very few sturgeon have been taken from Playgreen Lake in recent years; production was formerly much higher (Appendix B). According to Weagle (MS 1973) the residents attribute this to a reduction of stocks, however lack of effort may also be a factor. Weagle reports that this fishery is conducted in the Playgreen channel between South and North Playgreen Lakes (Figure 1). A former long-time resident and fisherman in the area, Mr. Nelson Scribe, reports that sturgeon were formerly fished extensively on the spawning grounds along the west shore of South Playgreen Lake.

Mercury contamination poses a fishery management problem in some of the upper Nelson lakes (Figure 16). Although none of the eight lakes under consideration in the present report are closed to fishing for this reason, mercury concentrations in pike at least are cause for some concern. Fish with more than 0.5 ppm mercury in the flesh are subject to rejection as unfit for human consumption.

6.7. Overview of fishery production potentials:

There is no truly reliable procedure for estimating the sustainable fishery capacity of lakes from the sorts of data available to the present study. This is especially the case for these particular lakes, with their "unusual" shallowness, turbidity, and rapid renewal. Empirically derived relationships such as Ryder's (1965) morpho-edaphic index appear essentially useless, except perhaps to establish a general overall point of reference. For a north-temperate lake with mean depth of 10 ft and TDS of 200 ppm (approximate modal values among these Outlet Lakes), Ryder's index predicts an annual sustainable fish yield of 8 lb/acre (all species). If we assume 60% "useable" species (again, an approximate modal value) we arrive at a sustainable yield estimate of about 5 lb/acre.

The suggestion was made earlier, in connection with the review of fish standing stocks, that Playgreen Lake might be slightly more productive of fish than the best Churchill-River lakes in Saskatchewan, that Kiskittogisu and Cross Lakes might be about equally as productive as these, and that Kiskitto Lake might be about as productive as the poorest Churchill-River lakes. The Churchill-River lakes have yielded from 2-4 lb/acre over the long term (Koshinsky MS 1971). On this basis, and attempting to take some subjective cognizance of the available water chemistry and bottom fauna values, we might expect the following

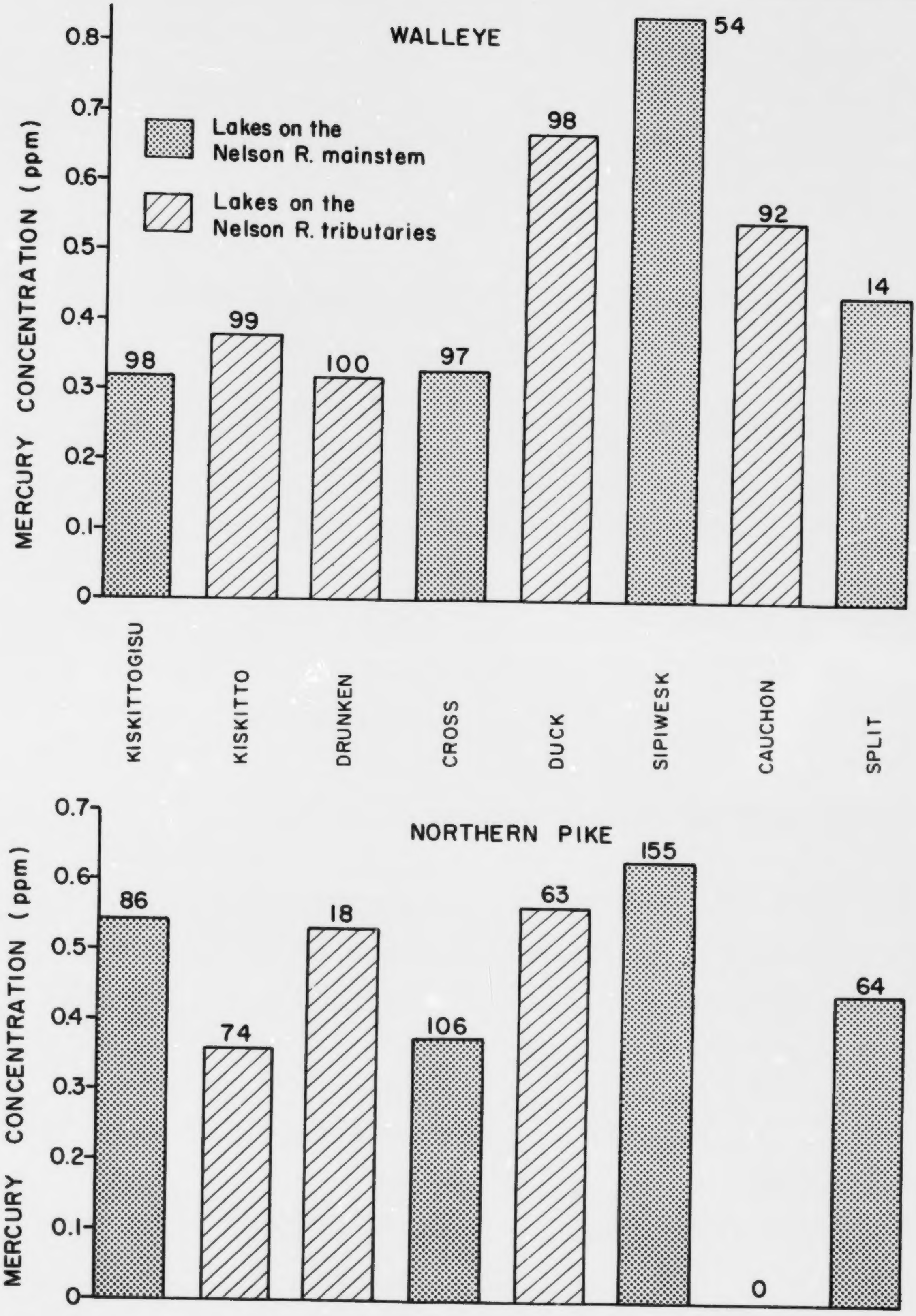


Figure 16. Mean concentration of mercury (ppm wet weight) in homogenized muscle samples of walleye and northern pike from eight lakes of the Upper Nelson River system, Manitoba, 1971-72. Numbers above bars indicate sample size. Data from Inspection Branch, Fisheries Service, Environment Canada.

approximate sustainable annual yields (commercial species only):

Lake	Expected annual yield	Recent observed yield
Playgreen	5 lb/acre	1.92
Kiskittogisu	3 lb/acre	0.31
Kiskitto	2 lb/acre	0.29
Little Playgreen	3.5 lb/acre	0.00 +
Pipestone	4 lb/acre	0.69
Cross	3.5 lb/acre	0.67 +
Drunken	5 lb/acre	3.43
Walker	4.5 lb/acre	2.67

+ indicates domestic fishing

These values compare in a general way with the "baseline" estimate from Ryder's morpho-edaphic index, taking some account of special negative factors of turbidity, extreme shallowness, and extremely rapid flushing. The individual estimates also show a positive relation to the recent observed production, although the actual production values have invariably been much lower. It might be noted in this connection that Schlick (personal communication) recently suggested that Playgreen Lake could probably sustain an annual fish harvest equivalent to 3.4 lb/acre.

The above are presented solely to establish a mental framework of "outside estimates" of what these lakes might ultimately be capable of producing, on the basis of their natural water regimes. The estimates should definitely not be interpreted as guidelines for current management under existing economic and technological constraints. Nor would these estimates seem particularly useful for predicting future fishery values. Such predictions are probably more reliably accomplished on the basis of recent actual production.

6.8. Economics of the commercial fishery:

Weagle (MS 1973) has compiled data and estimates on commercial fishing participation, returns to fishermen, fishing costs, and fish pricing as related to the Outlet Lakes area. The following account is adapted from his report. A tabulation of past trends in these particular aspects (1955-1969) for the more general Canadian or Manitoba freshwater fishing industry is given in Table 19.

6.8.1. Fish pricing considerations:

Trends in price to fishermen of four fish species taken in the Lake Winnipeg Outlet Lakes are included in Table 19. Since 1969, the Freshwater Fish Marketing Corporation (FFMC) has been purchasing the catch of commercial fishermen, and marketing and trading in these fish and fish products, in the participating Canadian provinces which include Manitoba. As stated in the Annual Report of the Corporation for 1969-70, "the Corporation has developed a system of initial and final payments and of pooling all receipts for respective species for this purpose. It has established lake prices as the basis for initial payments, achieving over the whole area a uniformity related to actual market prices adjusted to correspond with incremental costs involved in moving and handling fish from lakes to market. It has been the purpose of the Corporation to establish initial prices as close as possible to the commercial value of the product and in final payments to distribute to the fishermen any excess of income over expense which the Corporation obtains in marketing".

The mechanics of the actual system of payments to fishermen for production under the Corporation as it applies in the Outlet Lakes area, is diagrammed in Figure 17. The Corporation typically contracts for services of private owners and co-operatives to act as agents to buy the fish from the fishermen and transport it to Winnipeg. The agents operate from an "Initial Price to Agent" listing, F.O.B. the secondary receiving facility in Winnipeg. This listing is prepared on the basis of expected market prices and is issued by the Corporation before each season (but is

Table 19. Trends in landings, values, participation, and prices of selected species in the Canadian freshwater fishing industry, 1955 - 1969. Data are from Economics Branch, Fisheries Service, Environment Canada, 1971 Report: Annual Statistical Review of Canadian Fisheries, Vol. 3.

	Manitoba			Total Canadian Freshwater Fishery				
	Landings 000 lb.	Landed Values $ 000	Marketed Value $ 000	Fishermen Engaged	Price to fishermen, ¢ per lb.			
					Whitefish	Walleye	Sauger	Perch
1955	34,936	3,477	6,044	17,810	16.9	15.7	12.4	11.7
1956	30,397	2,947	6,426	15,781	-	-	-	-
1957	31,571	3,279	5,929	17,918	-	-	-	-
1958	31,929	3,540	6,844	20,074	-	-	-	-
1959	31,052	3,757	6,689	18,307	-	-	-	-
1960	31,944	3,867	7,035	17,666	12.9	21.7	22.1	10.2
1961	30,658	3,174	6,214	16,903	14.0	18.4	17.2	10.2
1962	36,105	4,229	7,979	16,684	14.4	21.6	20.8	6.2
1963	35,738	4,356	7,563	17,305	13.4	23.1	21.7	7.7
1964	28,636	3,720	6,888	16,246	15.1	25.0	20.6	17.1
1965	29,588	4,370	7,331	15,822	16.1	32.3	31.7	12.4
1966	29,933	4,788	7,082	15,328	17.0	35.7	30.2	8.9
1967	20,841	2,527	4,011	13,931	17.3	23.8	15.6	10.5
1968	25,734	3,276	7,255	11,350	20.5	28.7	16.7	8.4
1969	21,388	3,354	6,700	11,110	22.2	36.8	28.1	10.8

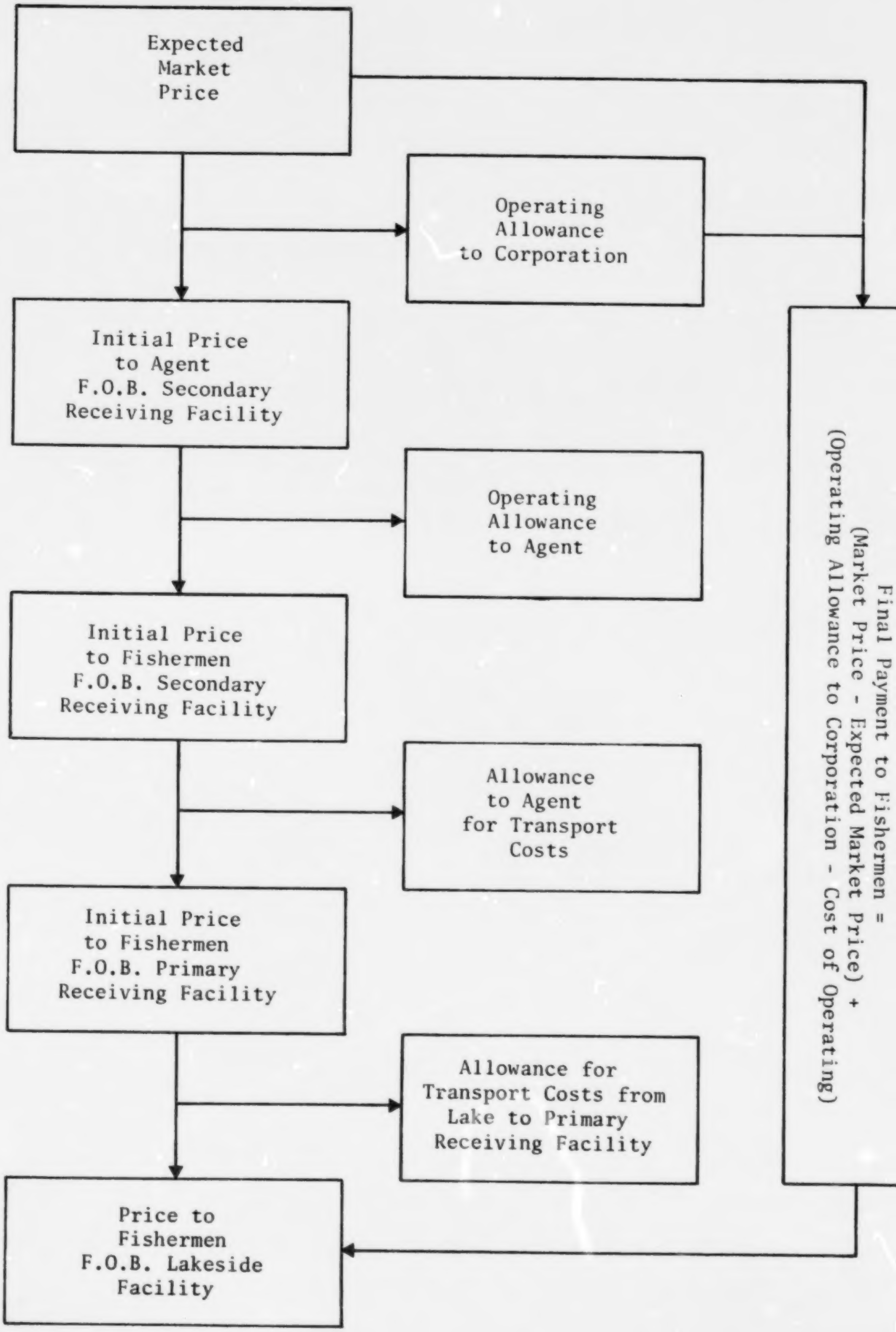

Expected Market Price
Operating Allowance to Corporation
Initial Price to Agent F.O.B. Secondary Receiving Facility
Operating Allowance to Agent
Initial Price to Fishermen F.O.B. Secondary Receiving Facility
Allowance to Agent for Transport Costs
Initial Price to Fishermen F.O.B. Primary Receiving Facility
Allowance for Transport Costs from Lake to Primary Receiving Facility
Price to Fishermen F.O.B. Lakeside Facility
Final Payment to Fishermen = (Market Price - Expected Market Price) + (Operating Allowance to Corporation - Cost of Operating)

Figure 17. System of payments for fish production under the Freshwater Fish Marketing Corporation.

subject to revision). This price includes the agent's operating allowance, apparently set at a flat 9¢/lb as at 21 February 1973 (Weagle MS 1973). The rationale for this allowance is 2¢ for administration, 2¢ for containers, and 5¢ for packing, labor, and ice. The "Initial Pric to Fishermen", F.O.B. the secondary receiving facility in Winnipeg, includes the operating allowance of the agent (Figure 17). Schedules o these Corporation initial prices to fishermen, F.O.B. the secondary receiving facility, are given in Appendix D. The fish quality categorie incorporate such considerations as size, rate of Triaenophorus infestation, fat content, color of the flesh, and other variables. A summar of the FFMC classification and rationale for the Lake Winnipeg Outlet Lakes as it pertains to whitefish is given in Table 20.

From the initial price F.O.B. the secondary receiving facility, th F.O.B. lakeside price to the fishermen is derived by deducting the agen transportation costs and allowances (see below). In addition a final payment may be forthcoming to the fishermen, depending on whether the realized market prices have exceeded the expected market prices, and allowing for operating and other costs of the Corporation (Figure 17). Final payments are calculated according to individual species or groups of species (e.g. "Mullets"). For 1969-70, final payments were made according to the following schedule:

	May 1 - Oct. 31	Nov. 1 - April 30
Whitefish	1.38 ¢/lb	-
Walleye, sauger	7.93	6.181 ¢/lb
Lake trout	5.20	9.226

No final payments were made in 1970-71.

Transportation costs and other information respecting movement of the commercial fish catch in the Outlet Lakes area is summarized in Table 21. At Playgreen Lake, fishermen deliver their catch directly to

Table 20. Freshwater Fish Marketing Corporation lake whitefish classification for the Lake Winnipeg Outlet Lakes.

Lake	Classification
Playgreen	1
Kiskittogisu	4
Kiskitto	4
Pipestone	1
Cross	1
Drunken	2
Walker	4

Classification -
1. Export Premium
2. Export Standard
3. Continental Premium
4. Continental Standard
5. Cutters

Export Premium	- fewer than 30 *Triaenophorus crassus* cysts/100 - light color flesh - high fat content
Export Standard	- fewer than 30 *T. crassus* cysts/100 lb - dark or light flesh - less fat content
Continental Premium	- between 30 and 80 *T. crassus* cysts/100 lb - dark or light flesh - high fat content
Continental Standard	- between 30 and 80 *T. crassus* cysts/100 lb - dark or light flesh - less fat content
Cutters	- more than 80 *T. crassus* cysts/100 lb - used only for fillets

primary receiving stations at Tait or Flett Islands, and hence are n subjected to deductions for this leg (Figure 17). The Playgreen fis also has the advantage of relatively inexpensive water transport to Winnipeg (Table 21). The historical procedure regarding the other O Lakes has been to fly the fish to Wabowden (intermediate point), shi them by truck or rail to The Pas (primary receiving station), and th on by rail to Winnipeg (secondary receiving station). Differential are incurred on the basis of flight distance from the lake to Wabowd The costs in Table 21 are for summer fishing; however according to W (MS 1973), the tendency is to use the same transportation modes in w as well. The propensity for mechanical failure in bombardiers appar gives preference to aircraft in moving fish from the lakes.

As noted above, the basic price to fishermen under the Freshwat Fish Marketing Corporation is based on market values. These values of interest not only in this regard, but also as they indicate the w of the fish to the consumer market. On the basis of data from 1955 through 1969 (Table 19), marketed values for Manitoba fish have exce landed values by an average of 1.84 times, with no indication of tre The impact of the Freshwater Fish Marketing Corporation in this rega has not yet been assessed. Detailed FFMC price quotations for fish p ducts are, however, available (Appendix E).

6.8.2. Values to fishermen, and numbers of participants:

Weagle (MS 1973) has plotted the values to fishermen and the nu of licences issued for each of the Outlet Lakes for the period of re These items are given by 6-year intervals in Appendix B, and are summarized for the 12-year period 1960-1971 in Table 18. All annual ave are based on the full record interval, rather than on the number of y t

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Table 21. Transportation modes, costs, and receiving points involved in the movement of the commercial fish catch from the Outlet Lakes to Winnipeg for the summer fishing season. Information for Playgreen Lake is for 1971; for the other lakes it is for 1970. All costs are in cents per pound.

Lake	Mode	Cost	Intermediate Point	Mode	Cost	Primary Receiving Station	Mode	Cost	Secondary Receiving Station	Total cost
Playgreen	Fishermen deliver directly to:					Tait Is. or Flett Island	Boat	4.75	Winnipeg	4.75
Kiskittogisu	Aircraft	4.1	Wabowden	Unrefrigerated rail, or refrigerated truck	1.8 2.5	The Pas	Rail	1.25	Winnipeg	7.15 to 7.85
Kiskitto	Aircraft	4.6	Wabowden	"	1.8 2.5	The Pas	Rail	1.25	Winnipeg	7.65 to 8.35
Pipestone	Aircraft	4.7	Wabowden	"	1.8 2.5	The Pas	Rail	1.25	Winnipeg	7.75 to 8.45
Cross	Aircraft	5.7	Wabowden	"	1.8 2.5	The Pas	Rail	1.25	Winnipeg	8.75 to 9.45
Walker	Aircraft	6.3	Wabowden	"	1.8 2.5	The Pas	Rail	1.25	Winnipeg	9.35 to 10.05

of actual fishing (see Appendix B). During this period, an average of about 116 fishermen produced about 522,400 lb of fish and received about $104,200 annually. Playgreen Lake has provided 58% of the fishery values for the Outlet Lakes, with Cross and Walker Lakes providing most of the remainder.

Income distribution among fishermen for four of these lakes for 1970 and 1971 is depicted in Figure 18. The bulk of the operators earn less than $3,000 per season. Comparisons are difficult because there is apparently no consistent definition of what constitutes an "operator" (Weagle, personal communication).

6.8.3. Costs of equipment and operating:

Costs pertaining to the transport of fish to the receiving facilities were outlined in Section 6.8.1. These costs represent deductions by the Corporation in the prices received by fishermen.

Weagle (MS 1973) has independently estimated capital costs (excluding fish houses), and operating costs (excluding transportation) for a one-man fishing operation for summer and winter fishing in the Outlet Lakes area. These estimates are given in Table 22. While some economies could probably be achieved by an operator fishing in both summer and winter seasons, these would likely be insignificant.

Winter fishing appears slightly more costly than summer fishing, attributable to the short life of a power toboggan compared with a boat and motor. The total cost of a winter operation is estimated at $1,483; that for summer fishing at $1,276. It will be noted (Figure 18) that a significant number of present operations are uneconomic according to these criteria.

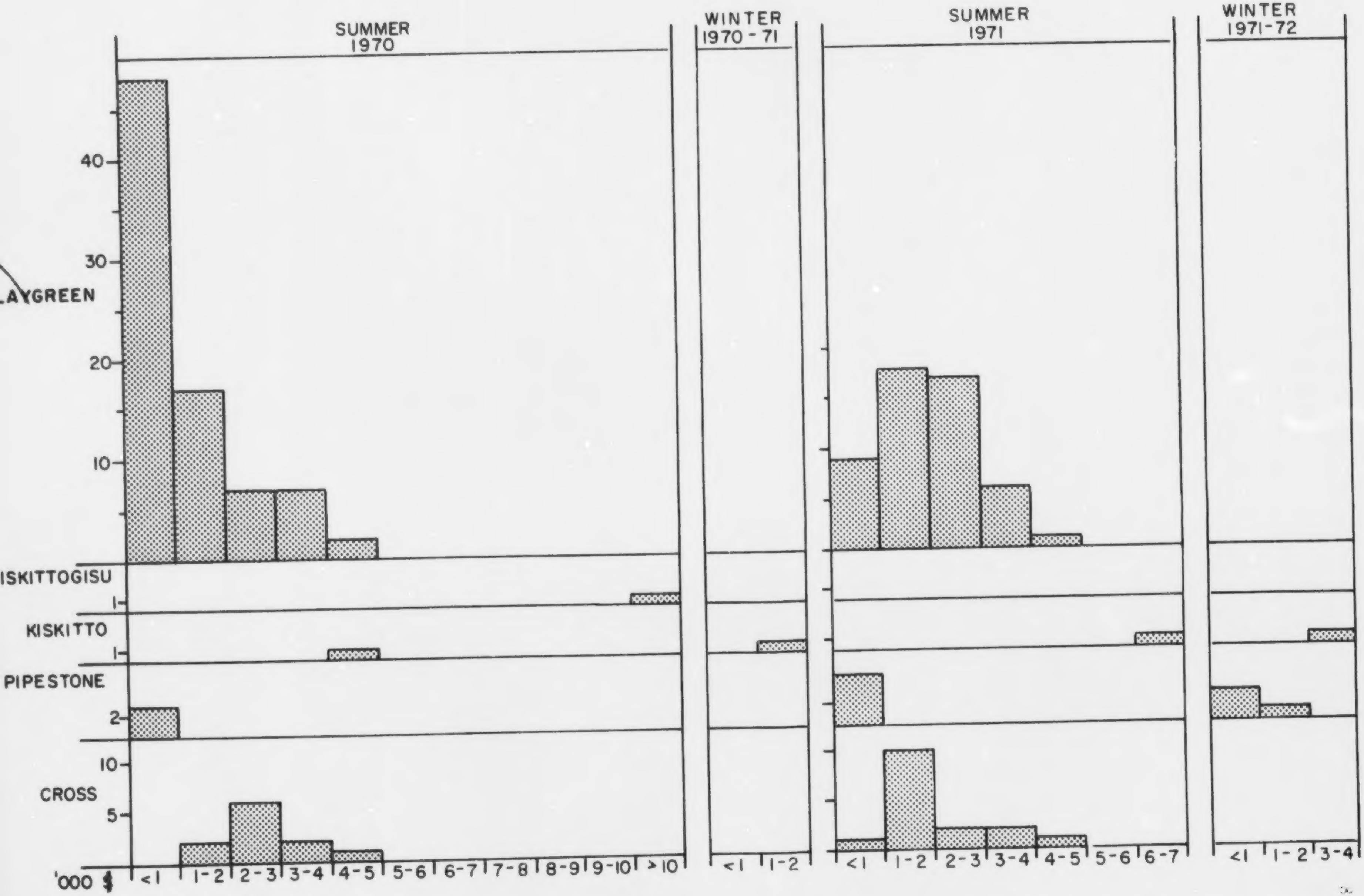

Figure 18. Frequency distribution of gross incomes, by $1,000 increments, of commercial fishery operators in four Lake Winnipeg Outlet Lakes according to summer and winter seasons, 1970 and 1971. Adapted from Beagle (MS 1973).

Table 22.- Estimated annual capital and operating costs for commercial fishing in the Lake Winnipeg Outlet Lakes. Estimates are given for separate summer and winter fisheries. Costs are in 1973 dollars. Estimates are adapted from Weagle (MS 1973).

Capital Costs				Operating Costs		
Item	Expected life, years	Initial cost	Amortized annual cost	Item	Annual cost	Total annual costs
A. SUMMER FISHING:						
Wooden yawl, 18 ft.	10	$ 700	$ 104	Licence	$ 15	
Outboard motor, 25 hp	5	600	150	Fuel & oil	340	
Gill nets (15)	2	450	262	Engine repairs	100	
				Rope	75	
				Misc.	230	
Totals			$ 516		$ 760	1276
B. WINTER FISHING:						
Power toboggan	2	$ 1000	$ 584	Licence	$ 15	
Sleigh	5	150	68	Fuel & oil	150	
Gill nets (15)	2	450	262	Repairs	100	
Tools	2	65	39	Rope	35	
				Misc.	230	
Totals			$ 953		$ 530	1483

ASSUMPTIONS:

1. One-man operation.
2. Fisherman operates for entire season.
3. Fisherman operates continuously for 10 years (summer fishery) and 5 years (winter fishery).
4. Equipment is used only for fishing.
5. Equipment has zero value at end of expected life.
6. Interest rate is 8%.

7. ISSUES AND IMPACTS

In the first part (7.1) of this section, those aspects of proposed hydro-electric construction and operation which could, according to present knowledge or anticipation, have some impact or potential impact on limnology-fisheries or on the utilization of the fishery resources in the Outlet Lakes area, are described in point form. More detailed project and operating specifications are available from other sources. Also listed, again in abbreviated format, are the pertinent (from the viewpoint of limnology-fisheries) direct physical effects which are expected to result from construction and/or operation. The anticipated impacts on limnology-fisheries of these physical effects are then set forth and discussed. Brief evaluation of the anticipated impacts, along with preliminary proposals for alternatives where such seem available, are presented for specific geographic components (lakes and river sections) in the subsequent parts (7.2 and 7.3) of this section. Project descriptions and anticipated direct effects were provided by Manitoba Hydro, by the Study Office, by various Study contractors, and from our own observations and deductions. Some of the hydrological data which form the basis for much of the discussion and evaluation are presented in Table 23. Features referred to are shown on the map, Figure 1.

7.1. Definition of issues and anticipated impacts:

7.1.1. Two-mile channel:

7.1.1.1. Project description:

a) A new water connection will be established between Lake Winnipeg and Playgreen Lake, about 10 miles west of Warren Landing.

Table 23. Summary of water levels and discharges in selected components of the Lake Winnipeg Outlet Lakes area under Lake Winnipeg regulation and for various Lake Winnipeg stage and total discharge conditions. From preliminary estimates (28 March 1972) by Manitoba Hydro Hydraulic Design Dept. (W.K. Mann, personal communication), without East Channel regulation.

	Maximum probable flood[a]	1966 flood[b]	Normal summer operation[c]	Normal winter operation[d]	Average March conditions[e]	Average April conditions[f]	Ponding
A. Elevations, ft above sea level							
Lake Winnipeg	722.15	716.25	714.60	713.87	713.84	713.82	715.0
D/S 2-mile channel	721.45	715.30	714.40	713.00	713.92	713.00	-
U/S 8-mile channel	720.90	714.75	714.33	712.05	711.67	711.62	-
U/S Kisipachewuk rapids	718.68	711.90	714.00	709.32	708.23	708.09	714.9
D/S Whiskey Jack Narrows	718.68	711.90	714.00	709.32	708.23	708.09	-
D/S Ominawin by-pass	716.65	708.35	713.82	706.18	704.75	706.30	-
Jenpeg forebay	711.70	702.30	713.50	703.30	702.00	705.00	714.9
Cross L. tailwater	691.5	687.3	679.3	685.0	-	-	674.0
B. Discharges, '000 cfs							
Warren Landing	192.0	119.5	43.2	60.3	49.9	49.9	
2-mile channel	80.0	62.5	26.4	36.7	38.3	38.3	}±27.8
East Channel	55.6	23.4	19.6	9.1	8.2	8.2	22.8
8-mile channel	80.0	57.5	18.3	28.7	26.8	26.9	
Whiskey Jack Narrows	136.4	101.1	51.7	59.3	53.2	53.1	}± 5.0
Kisipachewuk Rapids	22.5	23.5	8.1	15.1	13.8	11.0	
Metchanais Channel	85.5	40.6	13.5	18.8	16.0	16.5	
Ominawin by-pass	53.4	74.6	18.1	42.5	39.6	43.6	
Ominawin Channel	55.0	19.9	10.3	12.5	10.6	8.9	
C. Maximum velocities, ft/sec							
2-mile channel	4.4	4.2	1.8	3.0	3.0	3.0	
8-mile channel	4.8	4.3	1.5	2.9	3.0	3.0	
Whiskey Jack Narrows	10.9	9.4	2.6	7.3	5.3	5.3	
Kisipachewuk Rapids	-	-	-	9.0	-	-	
Ominawin by-pass	1.6	3.2	0.7	2.7	2.9	2.4	
Ominawin Channel	6.4	7.3	1.3	4.1	4.1	3.2	
Manitou Rapids	7.7	8.2	1.9	5.3	5.2	4.3	

[a] 10,000-year flood; and assuming Lake Winnipeg starts at 714.0 ft.

[b] Historic maximum; and assuming Lake Winnipeg starts at 715.0 ft.

[c] Approximate normal open-water conditions, May-October.

[d] Average January and February conditions; and assuming Lake Winnipeg at long-term average operating level of 713.87 ft.

[e] Assuming Lake Winnipeg at long-term average operating level of 713.84 ft.

[f] Assuming Lake Winnipeg at long-term average operating level of 713.82 ft.

b) The connecting channel will be about 28 feet deep, and about 400 feet wide at the base.

c) The channel will discharge continuously, without integral control.

d) Anticipated normal water discharge in the channel will range from about 26,400 - 38,300 cfs.

e) Maximum anticipated normal discharge velocity in the channel will be about 3.0 cfs.

f) Winter road access and power transmission facilities are already established to the channel site from PTH 6.

g) Excavation will be primarily by hydraulic dredge, with spoil deposition to take place within 10,000 feet of either side of the channel.

7.1.1.2. Direct effects:

a) Establishment of new boat access opportunity between Lake Winnipeg and Playgreen Lake.

b) Reduction of Nelson River discharge through Warren Landing by about 40%.

c) Provision for influx of water with potentially different source characteristics from Lake Winnipeg into South Playgreen Lake.

d) Provision of a potential fish access corridor between Lake Winnipeg and South Playgreen Lake.

7.1.1.3. Anticipated impacts on limnology-fisheries:

It is anticipated that during periods of strong onshore winds at the 2-mile channel entrance, a greater load of suspended sediment material will be transported into Playgreen Lake than now enters via Warren Landing. Galay (MS 1971) has identified an eastward littoral drift component along the north shore of Lake Winnipeg to the Warren Landing area; however rate of transport of material appears to be slow. Perhaps more significant is a northward drift into the outlet area along the east shore. This shore has extensive bedrock and coarse materials (Dowling and Tyrrell 1900) which, as is evident from Secchi disc transparency readings (Brunskill, personal communication), impart a lesser sediment load than the glacio-lacustrine clays and silts of the north shore. The north shore deposits produce a very pronounced local turbidity during onshore winds (Galay MS 1971). This effect, augmented by such shore drift as may exist at the 2-mile channel entrance, will presumably provide sediment-laden water for injection through the new channel into Playgreen Lake. This will occur during the ice-free period when winds are southerly. Galay (loc. cit.) could not estimate the magnitude of this predicted sediment transport phenomenon; it is also impossible to predict its effects. Presumably this impact will be most noticeable (compared to present conditions) in Playgreen Lake between the 2-mile and 8-mile channels, and perhaps in Little Playgreen Lake and the East Channel. Although primary productivity (phytoplankton and other vegetation) is handicapped by turbidity, indications are that this is very much the case even at present, so that very significant further negative effects in this regard are not expected. Some complications may arise from sedimentation. This could have implications for:

1) Bottom fauna production in South Playgreen Lake.

2) Shore-spawning sturgeon along the west shore of South Playgreen Lake (rumoured only). Sturgeon spawn in June, and the eggs would be highly vulnerable to sedimentation.

3) Spawning of whitefish in the East Channel and in Little Playgreen

Lake. Since this occurs at the very end of the open-water period, and since the eggs hatch just before or during breakup, there would seem to be little danger of serious negative effects.

Some positive influence of the 2-mile channel on bottom fauna productivity could be anticipated in the extreme south end of Playgreen Lake. One manifestation of reduced flows could be a greater production of mayflies, particularly the large and important Hexagenia sp.

It cannot be predicted whether fish will use the 2-mile channel for migration; in any case it is difficult to envisage any potential benefits of such activity. Anticipated channel velocities should not deter adult fish of the available species from moving freely through the channel in either direction. There is a possibility that the new channel might confuse present migration patterns, and perhaps disrupt what appears to be an important movement of whitefish from Lake Winnipeg into Little Playgreen Lake to spawn. The observations of Pollard (personal communication) suggest that movement of whitefish in the north basin of Lake Winnipeg is primarily in a clockwise direction so that fish moving to Warren Landing would tend to approach from the west. They would thus encounter the 2-mile channel prior to reaching the natural discharge corridor at Warren Landing, and might become disoriented.

The local implications of the improved water access opportunity for transport of the commercial fish catch are not great since adequate access already exists through Warren Landing. However barges apparently encounter some difficulties at Warren Landing during extreme low water, and this would presumably be avoided. On the other hand, a measure of benefit in this regard is implicit in Lake Winnipeg regulation per se; this will add about 1 ft to Lake Winnipeg levels in drought periods during the summer fishing season. Re-location of barge traffic from Warren Landing to the 2-mile channel would presumably require construction of extensive docking facilities on the downstream end (in Playgreen Lake).

It is noted that implications of the 2-mile channel for commercial transport of fish cannot be evaluated for Playgreen Lake alone. In view of other developments, both underway and potential, the Kiskittogisu Lake fishery must also be considered, and possibly that of Cross Lake and its neighboring lakes as well (Rosin et al. MS 1973).

7.1.2. Eight-mile channel:

7.1.2.1. Project description:

a) A new water connection will be established between Playgreen and Kiskittogisu Lakes, entering at the extreme south end of the latter.

b) The channel will be about 425 feet wide at the base, 20-25 ft deep, and will discharge continuously without integral control.

c) Anticipated normal discharge in the channel will range from about 18,300 - 28,700 cfs.

d) Maximum anticipated discharge velocity in the channel will be about 2.9 ft/sec.

e) Winter road access and power transmission facilities are already established to the channel site from PTH 6.

f) Excavation (already underway) will be by hydraulic dredge, with spoil deposition within an allowable area of about 50 square miles adjacent to the channel.

g) Extensive dyking will be undertaken in an effort to contain and direct the flow and deposition of dredge spoil.

7.1.2.2. Direct effects :

a) Marked improvement in boat access opportunity between Kiskittogisu Lake and Playgreen-Lake Winnipeg.

b) Direction of a major portion of the Nelson River West Channe discharge (about 35% under normal conditions) through the length the main basin of Kiskittogisu Lake.

c) Reduction of the Nelson River discharge through Whiskey Jack Narrows by an amount equivalent to the 8-mile channel flows.

d) Provision of a possible fish passage corridor between Kiskit Lake and Playgreen-Lake Winnipeg.

e) Significant increase in water levels in Kiskittogisu Lake at times of the year, as indicated by the following comparative ran

	Mean monthly levels	
	Modified historic	Regulate
Minimum annual	703.60 (Jan.)	706.58 (
Average annual	709.67	712.25
Maximum annual	712.75 (July)	714.95 (

Whereas the expected mean monthly maximum elevation under pr use is 712.75 ft (occurring in July), the present maximum elevat will be exceeded in about 40% of months (on a mean monthly basis under regulation, and will be exceeded in about 80% of years dur August and September.

f) Extensive flooding, especially around the low south end of Kiskittogisu Lake (approximately 20 sq miles in this area alone) a virtually continuous basis.

g) Establishment of new shorelines around large parts of Kiskit Lake.

h) Diversion of Kiskittogisu River from its present course, and modifications to habitat in the associated lagoons and tributari

7.1.2.3. Anticipated impacts on limnology-fisheries:

The higher water levels in Kiskittogisu Lake resulting from the 8-mile channel (in conjunction with Jenpeg operation) are of basic environmental concern. Presumably new and higher shorelines will be established around substantial parts of the lake, and particularly along the south side. Stabilization of shores on the south side will be delayed according to the effectiveness of the proposed dyking system (aimed at containing the new channel, and preventing entry of dredge spoil directly into Kiskittogisu Lake) in excluding wave action from the area. It is anticipated that a considerable quantity of floating peat, peat islands, and forest debris might be generated by the elevated lake levels, particularly in the low-lying south end. The ultimate disposition of peat materials in the Kiskittogisu River area would depend on:

1) The extent to which the peat is covered by dredge spoil.
2) Effectiveness of the dredge spoil cover in holding the peat.
3) Wave access to the area, particularly as affected by the dyking.

Floating of peat material would have severely detrimental local environmental effects, while movement of the material out of the area would affect aquatic habitats downstream. A worthwhile environmental objective might be to strive for a rapid termination of such effects by attempting to quickly stabilize the new shores. This might involve removal of forest cover to or slightly above the new high-water line, cessation of the dyking works, and perhaps even cessation of mechanized excavation of the actual channel beyond a certain distance. All these alternatives have major possible erosional consequences and could not be evaluated without a great deal more time and information.

The renewal time for the main south basin of Kiskittogisu Lake be decreased from an estimated 2-3 years at present, to 11-17 days u normal operating conditions, upon completion of the 8-mile channel. This should:

1) Provide a more favorable loading regime of nutrients, algae, allochthonous organic matter from Lake Winnipeg into Kiskittogis Lake, but at a renewal rate which is not prohibitively rapid.

2) Clear Kiskittogisu Lake of some of its internally-induced tur ity generated during the open-water season.

Presumably these developments will augment the productivity of important bottom fauna organisms as Pontoporeia, Sphaerium, and Eph but will probably be somewhat detrimental to Hexagenia. The greate amplitude of annual water level fluctuations, on the other hand, wi probably have some negative impact on bottom fauna production. The would be true of any sedimentation produced by outwash from dredge deposits and/or from the new and higher shorelines. In general, ho it is predicted that the new water regime will tend to favor bottom (and whitefish) productivity in Kiskittogisu Lake. Standing crops these organisms should come to more closely resemble those now occu in South Playgreen Lake (a 2-3 fold increase might legitimately be pated). There could be a significant improvement in whitefish condi and fat content, perhaps eventually resulting in a "Premium" classi cation regarding the commercial fishery.

Northern pike should be favored by the new and higher water re in Kiskittogisu Lake. It is unlikely that any such increase in pik abundance will further jeopardize the quality of the whitefish, as rate of Triaenophorus infestation is already quite high (Table 20). There might be a problem regarding whitefish recruitment. Kiskittog Lake has relatively little "preferred whitefish spawning habitat" (Table 4).

Destruction of the present Kiskittogisu River and lagoon system at the south end will probably have a serious negative effect on the walleye population in particular. It seems likely that this is the major spawning-rearing area, accounting for the fine walleye stocks the lake at present. Walleye productivity could be expected to drop to about half its present level or less, of the order of that now encountered in South Playgreen Lake.

Productivity impacts of the 8-mile channel will also be felt in North Playgreen Lake and in the Playgreen Channel. The slower water renewal time through this area (from about 5-9 days under normal conditions at present, to about 7-13 days under regulation) should increase bottom fauna and whitefish production. There will also be so negative impact on winter oxygen concentrations, which are already l in this part of the Playgreen-Kiskittogisu system; however this effe unlikely to be significant.

Utilization of the 8-mile channel by fish species is impossible predict. It might provide an avenue of recruitment of whitefish and walleye young into Kiskittogisu Lake.

The channel will allow barge access from Lake Winnipeg, which should facilitate movement of the commercial fish harvest in summer. commercial fishery will probably become more integrated with that on South Playgreen Lake, and may in future be more effectively conducte operators from Norway House than from Cross Lake. Debris resulting su

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from innundation will have some negative effect on commercial fish

7.1.3. Ominawin by-pass and other channel "improvements":

7.1.3.1. Project description:

a) A new channel will be excavated through Metchanais Island,
by-pass to carry about 35-55% of West Channel flows under norma
operating conditions.

b) Considerably lower velocities will occur in the by-pass cha
(normally 0.7-2.7 ft/sec) than in the natural Ominawin channel
4.1 ft/sec) or in Whiskey Jack Narrows (2.6-7.3 ft/sec) under r
lation.

c) Some minor channel "improvements" are also scheduled for Kisipachewuk Rapids.

7.1.3.2. Direct effects:

a) Improved boat access link between Jenpeg and Kiskittogisu L
(via Ominawin by-pass channel).

b) Reduced discharge at Kisipachewuk Rapids, Metchanais Channe
and Ominawin Channel.

7.1.3.3. Anticipated impacts on limnology-fisheries:

Little or no predictive capability exists regarding impacts o
stocks in these Nelson River channel areas. These channels appear
have the most attractive pike populations for sport fishing in thi
vicinity, and presumably physical disruptions of habitat would be
advantageous. On the other hand, reduced discharge volumes in the
channels should generally benefit pike, and perhaps walleye as wel
The Ominawin by-pass will ensure easy boat access to these areas,
also to Kiskittogisu-Playgreen-Lake Winnipeg, from road's end at
Jenpeg site.

7.1.4. Jenpeg installation:

7.1.4.1. Project description:

a) Control will be established over the West Channel Nelson River discharge.

b) Total turbine capacity (6 units) rated at 93,000 cfs at a 24-foot head.

c) Turbine intakes located near bottom elevation of installation.

d) Gated spillway to provide excess discharge capacity to accommodate (in conjunction with turbines) maximum probable flood. Spillway gated to discharge through full vertical range.

e) Minimum allowable forebay elevation will be 702 feet.

7.1.4.2. Direct effects:

a) A forebay environment will be established, involving a maximum depth increase of about 37 feet and a maximum inundation of 37 square miles, both values on the basis of the 715-foot contour (Lamont MS 1972).

b) A tailrace environment will be established below the installation.

c) West Channel discharge could be reduced to ±5000 cfs during the initial ponding period.

d) Permanent road access and permanent paved airstrip are already in operation.

e) The installation, if unmitigated, will block opportunity for fish passage out of Cross Lake, and will expose downstreaming fish and other organisms to turbine hazard.

7.1.4.3. Anticipated impacts on limnology-fisheries:

The Jenpeg forebay area is likely to be unproductive of bottom fauna and most fish species because of the extensive seasonal fluctuation in levels (about 12 ft in an ordinary operating year). Northern pike, however, are known to do well in new impoundments, at least initially. Clearing of forest cover in the forebay, now underway, could be an important enhancement for the recreational potential. However, clearing specifications (personal communication from Mr. W. G. Bowen) appear rather lenient (e.g. "Where the river banks have a mild slope and flooding will occur over a wide area along and away from the natural river channel, clear (only) to elevation 710 feet"). It would seem that this, and the apparent attention only to areas with merchantable timber, will still allow extensive forest inundation. Pike should benefit from such inundation, but exploitation of this resource will be made more difficult by the debris. Unless a virtually complete clearing program were undertaken, it is unlikely that a commercial gillnet fishery could develop in the forebay in the foreseeable future.

The Jenpeg structure, without remedial facilities, will completely block any upstream fish migrations which may occur in this river section. Manitoba Hydro are undertaking to provide a fish-attracting facility which, if fish are found to enter it, will presumably be expanded and incorporated into a permanent fish passage facility. A co-operative working arrangement has been established between Manitoba Hydro and Fisheries Service engineers to prepare the necessary specifications, and designing is well underway (Weagle MS 1973). This work has, to date, been undertaken outside the auspices of the Canada-Manitoba Churchill-Nelson Study Agreement. In the absence of data on fish migrations, it is impossible to evaluate the need for such a facility at the present time. It would seem that if such migrations were extensive, there would be some indication of them in the history and habits of the native peoples. If a significant spawning run of, say, walleyes does take place through this reach, much of its basis may be lost for other reasons, i.e. by the elimination of access to Kiskitto Lake, by the destruction of Kiskittogisu River and lagoons, and by changed water regimes in the Nelson River channels. As pointed out by Weagle (MS 1973) however, the Canada Fisheries Act does call for fish passage facilities at all artificial obstructions on Canadian waterways.

The Jenpeg tailrace should provide excellent sport-fishing opportunity for northern pike, and perhaps for walleye. Permanent road access is apparently assured, and this along with the viewing option regarding the hydro-electric installation should promote extensive sport-fishing activity. Jenpeg will undoubtedly serve as a departure point for fishing trips up the West Channel to Kiskittogisu Lake and beyond. Commercially-harvested fish could be brought here from both upstream (Kiskittogisu-Playgreen) and downstream (Cross Lake, etc.) for transshipment to truck for furtherance to Winnipeg. Numerous other new transportation alternatives are available, including transshipment from the Minago crossing and/or a lock at Jenpeg (see Rosin et al. MS 1973).

7.1.5. Permanent road to Jenpeg:

7.1.5.1. Project description:

a) All-weather road already established, commencing from PR 391 just south of Wabowden. This road is owned and maintained by the Province of Manitoba.

b) Road crosses Minago River just above Cross Lake; crossing is temporary at present.

c) Bridgehead at Nelson River West Channel provided by Jenpeg control structure.

7.1.5.2. Direct effects:

a) Establish new all-weather vehicle access to the West Channel.

b) Provide option for extension of road access, or for development of winter road facilities, from the West Channel to Norway House and Cross Lake communities.

c) Provide road-boat access to Drunken and Hill Lakes, and the west end of Cross Lake.

7.1.5.3. Anticipated impacts on limnology-fisheries:

The main impact will be in the increased opportunities to exploit fish stocks and/or to move the products of commercial fishery exploitation more cheaply. The latter aspects have been summarized by Rosin et al. (MS 1973).

According to W. Schick (personal communication), boat access is possible at ordinary water levels to both Cross and Drunken Lakes from the road crossing point. This could have important implications for sport and commercial fish exploitation on both these lakes, and would particularly augment the value of the fine walleye stocks in the Drunken Lake-Minago River system.

The Minago River crossing is now accomplished on a temporary culvert arrangement which will presumably be replaced by a permanent bridge. Appropriate precautions will have to be taken at that time, and should also be implemented for the present temporary arrangement, to ensure that fish passage in the river is not jeopardized by obstructions, iceing, or velocity characteristics imposed by the crossing structure.

7.1.6. Operation of Lake Winnipeg control (i.e., operation of Jenpeg):

7.1.6.1. Project description:

a) West Channel discharge will be controlled with the following objectives:

i) Maintain Lake Winnipeg within a 4-foot operating range (711-715 feet).

ii) Meet electricity demands.

b) The minimum licenced total discharge to Cross Lake (West and East Channels combined) is 25,000 cfs. However simulation runs only get down to about 40,000 cfs, and then only occasionally (W. Mann, personal communication).

7.1.6.2. Direct effects:

a) Marked reduction in summer discharge, and an equally marked increase in winter discharge, from Lake Winnipeg and in the Nelson River West Channel (Figure 19).

b) Significant increase in water levels in Playgreen and Kiskittogisu Lakes at all times of the year, and with the general magnitude of the increase indicated as follows (based on mean monthly levels):

	South Playgreen	North Playgreen	Kiskittogisu
Minimum annual	+3.07	+3.65	+2.98
Average annual	+1.52	+2.15	+2.58
Maximum annual	-0.51	+0.17	+2.20

c) More marked seasonal fluctuations in water level, particularly in North Playgreen and Kiskittogisu Lakes, and in discharge in the West Channel.

d) Much greater magnitude of water level increase between April-May and of water level decrease between October-November in North

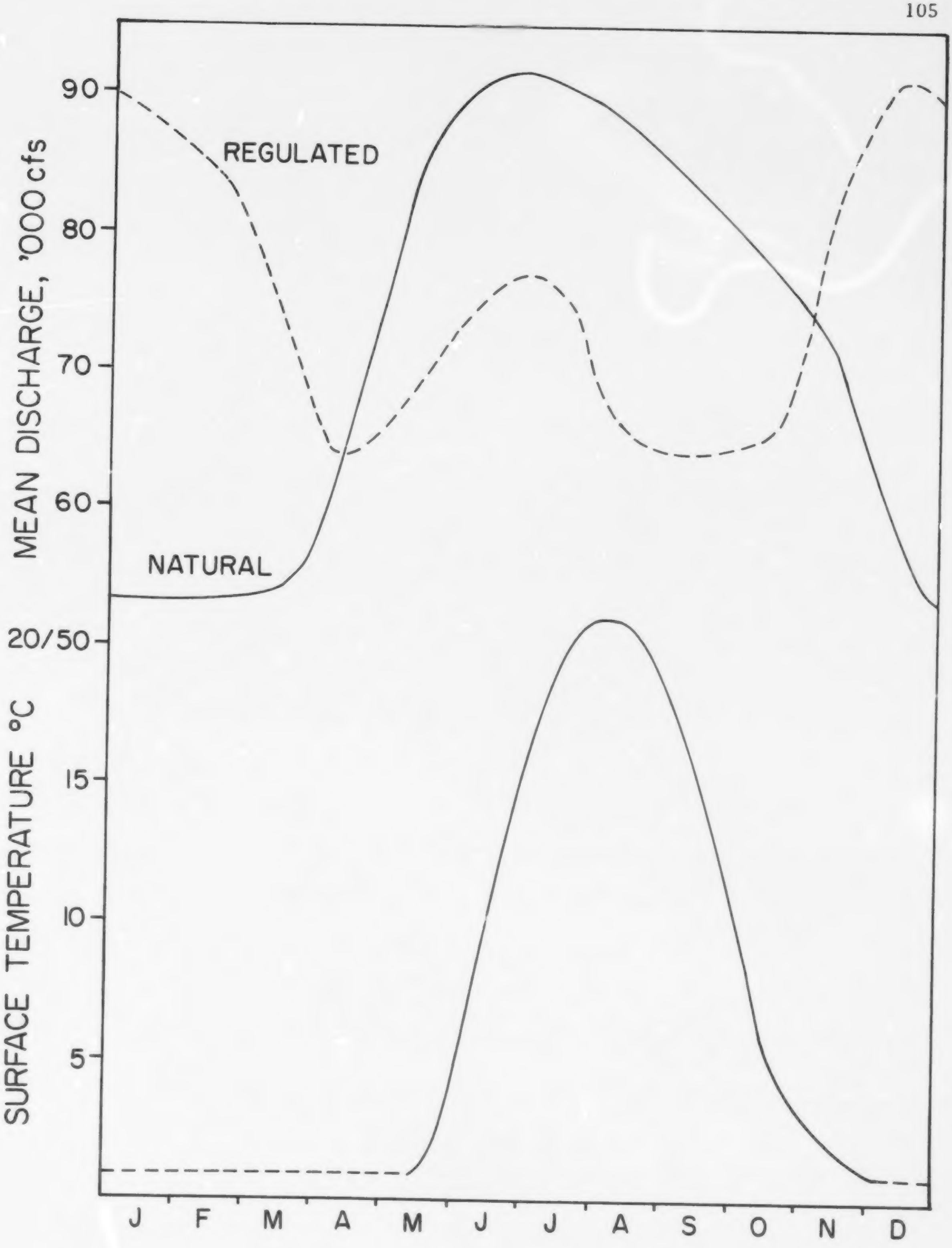

Figure 19. Seasonal pattern of discharge from Lake Winnipeg for natural and regulated conditions (upper lines), and of surface temperatures in the north basin of Lake Winnipeg (lower line). See text for sources.

Playgreen and Kiskittogisu Lakes (Figure 20).

e) Slightly greater mean monthly discharge (all times of the year), and considerable amelioration of both minimum and maximum discharges in the East Channel (in absence of East Channel control).

f) A reversal of the natural water regime on Cross Lake, with somewhat higher regulated levels during December-April, and somewhat lower levels during May-November, with the greatest change from natural mean monthly levels being a 2.85-foot decrease (in August).

g) Much greater month-to-month water level fluctuations on Cross Lake with regulation, involving mainly increases from October through January, mainly decreases from February through April, and increases or decreases at other periods. Levels will remain within the historic range.

7.1.6.3. Anticipated impacts on limnology-fisheries:

There will be a significant decrease in annual heat transport from Lake Winnipeg into the Outlet Lakes due to increased discharge in winter when Lake Winnipeg is cold, and decreased discharge in summer when Lake Winnipeg is warm. These relationships are shown in Figure 19. (Thermal data for Lake Winnipeg are from R. Rybicki, personal communication; discharge data are from Manitoba Water Resources Branch Report 1972a.) This may have some adverse effect on biological productivity, although actual temperature shifts would presumably be slight. Some important bottom fauna species, such as *Pontoporeia affinis* might actually be favored.

Of possibly greater significance is the reduced spring discharge, which might retard breakup, but which is counterbalanced by the greater late-autumn discharge, which will presumably retard freeze-up.

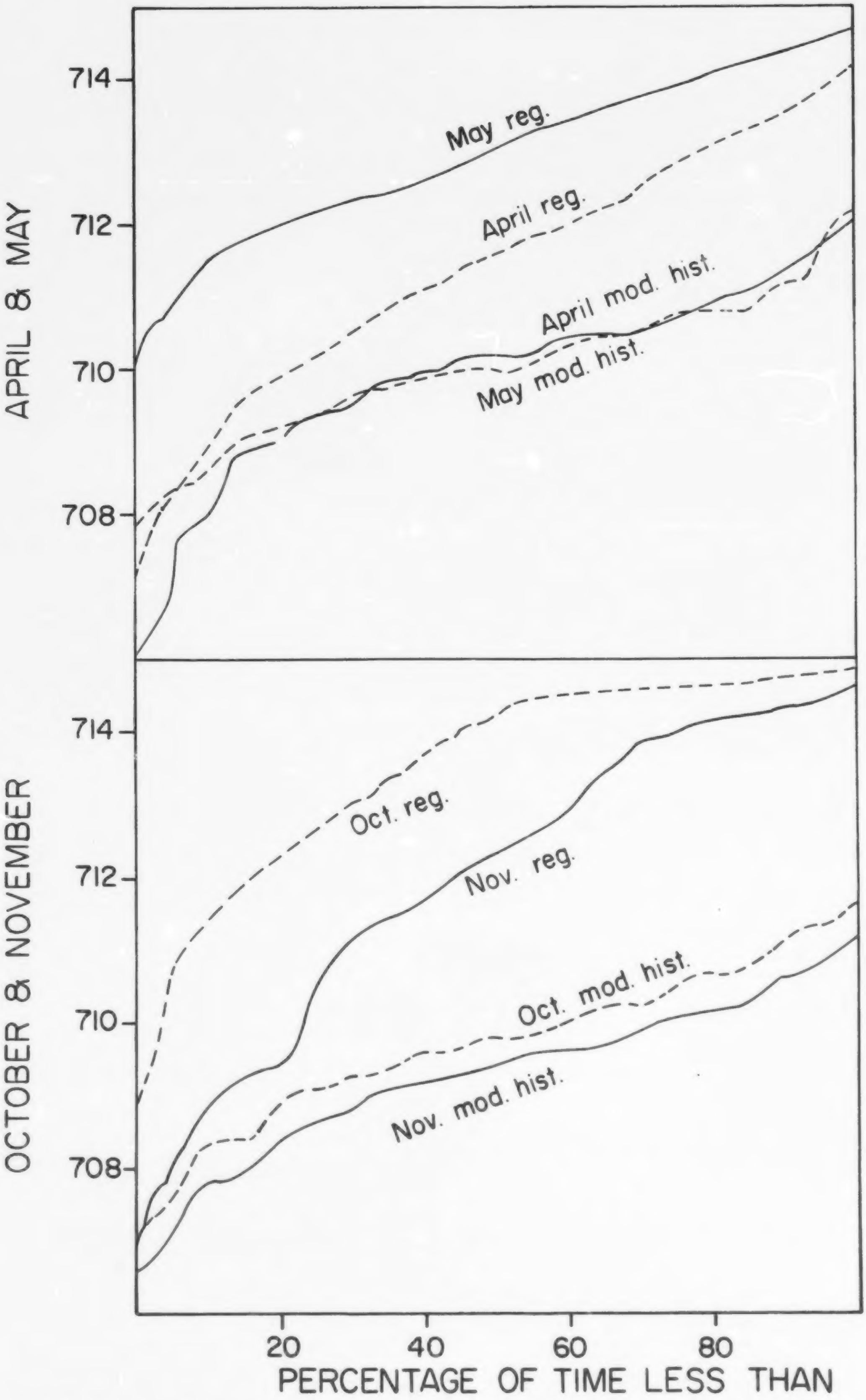

Figure 20. Mean monthly level stage duration curves for Kiskittogisu Lake for four months for both regulated and modified historic (present use) conditions. Data from Manitoba Water Resources Report 1972.

The anticipated effects of increased water levels on Kiskittogisu Lake, including establishment of new shorelines, have already been noted. In the absence of appropriate mapping and other information thi aspect cannot be considered in detail, although there may be some important impacts. Elevations will also be substantially increased on North Playgreen Lake; however in this case the levels will remain primarily within the natural range, so shoreline readjustments should not be significant.

The greater seasonal fluctuations in water levels in North Playgre and Kiskittogisu Lakes will be to the detriment of the littoral fauna. The much greater April-May increase in levels under regulation should b advantageous for pike reproduction. However the increased occurrence and amplitude of water level reductions between May and June could adversely affect incubation of walleye eggs in these areas. The much greater induced drop in levels between October and November (Figure 20) should be too early in the season to seriously affect whitefish incubation.

Reduction of discharge in the West Channel in summer under regulation should improve the prospects for a tailrace sport fishery below the Jenpeg installation. The large annual fluctuation in elevation in the forebay itself will be a serious constraint in forebay productivity This will essentially preclude successful reproduction of autumn-spawning fishes, and will seriously impair production of bottom fauna. These factors, along with debris problems, make it unlikely that the forebay will have a significant commercial fishery potential.

The much greater month-to-month fluctuations in flows in the various branches of the West Channel will be detrimental to the reproduction of any fish species (e.g. walleye) which may take pla in these channels.

The more stable and somewhat greater flows in the East Channe (assuming no control structure here) would presumably be beneficia to most of the aquatic life including, perhaps, incubation of whit fish eggs upstream in Little Playgreen Lake.

The forecast reversal of seasonal regimes and the greater mont to-month fluctuations for Cross Lake (Manitoba Water Resources Rep. 1972) are of considerable concern. However the new regime will be established well within the historical elevations and since the lak so very shallow, the limnological benefits of higher winter levels tend to compensate the limnological disruptions due to fluctuations Some disbenefits are anticipated for pike reproduction from the muc greater probability and magnitude of anticipated declines in water during April-May. Probably of greatest concern is the disruption i human mobility which is expected to accompany the new water regime. general trend to rising lake levels during and immediately after fr up will make ice conditions difficult for winter fishing. The lowe (2-3 feet) levels during July-August under regulation will probably affect boating mobility and could prevent boat access from Cross La to the adjoining lakes such as Walker, Drunken, Hill, and Pipestone commercial and sport fishing. Profiles of interconnecting channels not available for evaluation but even within Cross Lake (Figure 6), mobility would probably be lost with a 4-foot drop (mean anticipate August level) from the soundings shown. The boat route to Walker L would appear particularly vulnerable to such a regime; the route to (or more particularly to the Minago crossing) would probably be les affected.

7.1.7. Regulation of Kiskitto Lake:

7.1.7.1. Project description:

a) The present Kiskitto Lake outlet will be blocked, presumably by a gated structure.

b) A channel will be dredged to Black Duck Creek to spill water from Kiskitto Lake. Design capacity will be about 300 cfs.

c) It is proposed to establish a weir on Black Duck Creek, to regulate Kiskitto Lake levels.

d) Stan Creek will be diverted into Kiskitto Lake.

7.1.7.2. Direct effects:

a) Prevention of water back-up from the West Channel into Kiskit Lake, a normal product of ice-jamming under natural winter conditions.

b) Regulation of Kiskitto Lake between about 696.0 and 698.3 fee or slightly higher, (cf. 686.5-702.0 feet historically).

c) Depending on regime adopted, possible significant erosion in the upper reaches of Black Duck Creek.

d) Alteration of the water regime of Black Duck Creek, and possi the regime and water quality characteristics of Drunken Lake and lower Minago River.

7.1.7.3. Anticipated impacts on limnology-fisheries:

Basic water exchange through Kiskitto Lake is relatively ineffi at present since the bulk of the water enters and exits via the same channel. However the magnitude of seasonal water level fluctuations (average 4.27 feet) is large relative to the mean depth of the lake, that about 60% of the water (on average) is replaced every year unde to

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natural conditions. This is equivalent to a constant discharge

326 cfs. Local inflows are minor by comparison.

The natural flushing is inadequate, in timing and quantity,
clear the lake of internally-induced turbidity. However it does
vide nutrient and ion loadings such that concentrations are simi
those in the other lakes. This exchange may also play a role in
taining winter oxygen levels. It would accordingly be desirable
the viewpoint of limnology-fisheries, to maintain a magnitude of
charge through the lake similar to, or even greater than, the na
exchange, particularly in winter. However an inflow of this mag
would create outflows which could not be accommodated by the out
channel without major additional expenditures (H. Hill, personal
communication). A compromise has been suggested, whereby approx
half the natural flushing action would be maintained, preferably
winter emphasis. A 72-inch gated culvert is proposed for the in
structure. This would be capable of delivering 430 cfs at a Wes
Channel elevation of 707 feet, and through a 12-foot head differ
(Manitoba Hydro Report 1972).

The much greater stability of water levels in Kiskitto Lake r
sultant from control should be very beneficial to bottom fauna a
production. It is anticipated that walleye, pike, and goldeye i
ticular will benefit, perhaps to a doubling of productive capaci
Whitefish food stocks should increase; however there may be prob
whitefish recruitment which cannot be assessed from present data
view of the very shallow depth of the lake, adoption of a regime
will tend toward the top of the natural range will have benefici
effects from the viewpoint of limnology-fisheries.

Erosion in the upper reaches of Black Duck Creek, and sedimentat in the lower reaches of the creek and in Drunken Lake, could be detrimental to the stocks of walleye and northern pike in the Drunken Lake Minago River system.

7.1.8. East Channel regulation:

7.1.8.1. Project description:

No specific engineering proposals have yet been advanced, but it is generally recognized that it would enhance the economics of the Outlet Lakes hydro-electric project if control were established on Ea Channel discharge. The basic objective would be to conserve water in summer during low-flow or following low-flow periods (W. Mann, persona communication). Presumably control would generally not be exercized i winter. Control could apparently be most readily accomplished by a lo dam (10-15 feet) at Sea River Falls. The forebay would probably be co tained within the existing banks. Such a dam would provide a bridgeh across which a road system could be developed between Jenpeg and the communities of Norway House and Cross Lake.

7.1.8.2. Direct effects:

a) Presumably decrease discharges in the East Channel, primarily i dry summers or after dry winters.

b) Create opportunity to move the commercial fish catch from Cross Pipestone, and Walker Lakes by road from Cross Lake community.

c) Enhance sport fishing access to the East Channel and nearby are

d) Create a small tailrace environment below the installation.

7.1.8.3. Anticipated impacts on limnology-fisheries:

Impacts other than improved access opportunities, are dependent o

the flexibility of the structure and on the discharge regime
Such a structure would block upstream fish migration; howeve
migrations have not been documented under the natural regime
sumably a preliminary fish attraction device could be incorp
with the possibility of converting it to a full-scale fish p
facility if a function were demonstrated. However in view o
head, the cost of building a complete passage facility at th
may not be significantly greater than the cost of an attract
only. The most satisfactory overall alternative may be to m
natural passage, perhaps in a secondary channel.

There is some probability that whitefish spawning and i
success in Little Playgreen Lake is related to some componen
winter discharge in the East Channel. Disruption of winter
anticipated) could produce some disbenefits in this regard.

The fishery resource of the East Channel per se is enti
known, but might be considerable. Sufficient discharge shou
tained to ensure at least some flow in all channels at all t
(personal communication) has suggested that flows in the Eas
should not be cut below 4800 cfs; however this was a prelimi
mendation based on an early interpretation of minimum histor
In the interest of any fish spawning which might take place
Channel(s), controlled discharges during May and June should
at a somewhat higher level (say 10,000 cfs minimum), and not
to fluctuate during this period.

Reduction of East Channel discharge would decrease nutr
algal loading to Pipestone Lake, undoubtedly to the detrimen
productivity there. It may be anticipated that productivity

in approximately the same proportion as any annual decrease in flow. No attempt has been made to predict the stage characteristics on Pipestone Lake following hydro-electric development. Depending on the nature of the connecting channels with Cross Lake, Pipestone Lake might drop to unprecedented low levels in late summer, especially if both East and West Channel flows were controlled.

7.2. Evaluation of impacts on fisheries:

The anticipated individual impacts on limnology-fisheries of the various effects of proposed hydro-electric development and operation in the Outlet Lakes area were described in the first part of this section. These anticipated impacts are summarized in relative terms for each of the affected areas in Table 24 (impacts on fish productivity), and in Table 25 (impacts on fish exploitation opportunities). An attempt is now made to quantify these anticipated impacts in terms of the fishery (all species combined) for each of the affected areas.

Considerable effort was expended trying to derive rigorous models with which impacts could be consistently predicted throughout the study area. It was found, however, that the amount of intuition required to quantitatively assess, weight, and integrate the meagre data components invariably overshadowed the data base and hence the contribution of the model itself. In view of this and other constraints it was decided to forego the rigorous modelling approach and to evaluate intuitively within the mental framework provided by the available data input.

For each regional component of the study area, composite indices of basic fish productivity and of fish exploitation opportunity following hydro-electric development were estimated on the basis of the impacts outlined in Tables 24 and 25. These indices (Table 26) apply to full development and operation according to the presently defined rules and specifications. Indices were rated around the base value 1, taken to represent present productivity and opportunity, i.e. without hydro development. Three time horizons were considered: 5, 15 and 50 years after development. The impacts on fish productivity are generally recruitment-linked and, at the prevailing growth rates, 5 years is a reasonable approximation of the

Table 24. Summary of anticipated impacts of various aspects of hydro-electric development-operation on productivity of individual fish species or species groups in the Lake Winnipeg Outlet Lakes area. The number of characters denote the magnitude of expected impact; the sign denotes the expected direction of impact.

Geographical component	Development or operation	Anticipated effect	Anticipated relative impact					
			Whitefish	Walleye	Pike	Goldeye	Sturgeon	Other
North Lake Winnipeg	2-mile channel	Disoriented migrations?	--?					
	Jenpeg operation	Stabilized East Channel flows	+					
	East Channel control	?	?	?				
South Playgreen Lake	2-mile channel	Increased turbidity	--	-	--		--	--
	2-mile channel	Reduced discharge south end	+	+	+		+	+
	Jenpeg operation	Elevated water levels	-	-	+		-	-
	Jenpeg operation	Increased water fluctuations	-	--	-		-	-
	Jenpeg operation	Reduced heat loading	+	-	-		-	-
North Playgreen Lake	2-mile channel	Increased turbidity	-					-
	8-mile channel	Longer renewal time	++	+	+		+	++
	8-mile channel	Reduced winter oxygen	-	-			-	
	Jenpeg operation	Elevated water levels	-	-	+		-	-
	Jenpeg operation	Increased water fluctuations	-	--	+		-	-
	Jenpeg operation	Reduced heat loading	+	-	-			
Little Playgreen Lake	2-mile channel	Increased turbidity	-					-
	Jenpeg operation	Stabilized East Channel flows	++	++	+			+
	East Channel control	Reduced summer discharge	-	-				
East Channel	Jenpeg operation	Amelioration of discharge extremes		++	+			+
	East Channel control	Reduced summer discharge		-	-			
Pipestone Lake	Jenpeg operation	Reduced summer levels		-	-			-
	East Channel control	Reduced nutrient loading	--	--	-	-		--
	East Channel control	Reduced summer levels	-	--	--	-		--
Kiskittogisu Lake	8-mile channel	Shorter renewal time	+++	+++	+++	-		+++
	8-mile channel	Increased water levels	-	-	++			-
	8-mile channel	Destruction of Kiskittogisu R.		---	--			--
	Jenpeg operation	Increased water fluctuations	-	--	+			-
Kiskitto Lake	Inlet obstruction	Reduced flushing	--	--	--	+		--
	Inlet obstruction	Reduced fish exchange ?	-	-		-		
	Inlet control	Reduced fluctuations	+++	+++	+++	++		++
	Inlet control	Increased average level	+++	++	++	++		++
	Stan Creek diversion	Habitat addition		++	++			++
West Channel(s)	Ominawin by-pass	Reduced flows		+	+			
	Kisipachewuk improvement	Reduced habitat		-				
	Jenpeg operation	Increased water levels	-	-	++	+		-
	Jenpeg operation	Increased water fluctuations	-	-	-	+		-
Jenpeg forebay	Jenpeg operation	Increased water levels	-	-	+++			-
	Jenpeg operation	Increased water fluctuations	---	--	-			--
Jenpeg tailrace	Jenpeg operation	Reduced summer flows		+	++			
	Jenpeg operation	"Deep-water" discharge		-?				
Cross Lake	Jenpeg operation	Increased winter levels	++	+	+	+		+
	Jenpeg operation	Reduced summer levels	-		-	-	-	-
	Jenpeg operation	Increased water fluctuations	-	-	--	+	-	-
Drunken Lake	Kiskitto control	Erosion Black Duck Creek	-	--	--	+		-
	Kiskitto control	Altered flow and quality, B.D.Cr.	?	?	?	?		?
	Jenpeg road	Interference with fish migrating?		-	-	-		
	Jenpeg control	Increased water fluctuations?	-	-	+	+		-
Walker Lake	Jenpeg control	Increased winter levels?	+					
	Jenpeg control	Reduced summer levels?	-		-			-
	Jenpeg control	Increased water fluctuations?			-			

Table 25. Summary of anticipated impacts of various aspects of hydro-electric development-operation on exploitation prospects and efficiency in the Lake Winnipeg Outlet Lakes area. The number of characters denote the magnitude of expected impact; the sign denotes the expected direction of impact.

Geographical component	Development or operation	Anticipated effect	Commercial fishing	Sport fishing	Dome fis
Playgreen Lake	2-mile channel	Access	++		
	Jenpeg operation	Elevated water levels	+		
	Jenpeg road	Access	+	+	
	East Channel control	Access		++	
Little Playgreen Lake	Jenpeg road	Access (if extended)		+	
	East Channel control	Access		+++	
	Jenpeg operation	Stabilized East Channel flows			
East Channel	Jenpeg road	Access (if extended)		+	
	East Channel control	Access (if extended)		+++	
Pipestone Lake	Jenpeg road	Access	++	+	
	East Channel control	Access (if extended)	+++	+++	
Kiskittogisu Lake	2-mile channel	Access	++		
	8-mile channel	Access	+++		
	8-mile channel	Shoreline inundation	--		
	Jenpeg road	Access	+	++	
Kiskitto Lake	Jenpeg road	Access (on extension)	+++	+++	
West Channel(s)	Jenpeg road	Access	++	+++	
	Jenpeg operation	Inundation	---	-	
Jenpeg forebay	Jenpeg road	Access	+	+++	
	Jenpeg operation	Inundation	---	-	
Jenpeg tailrace	Jenpeg road	Access		+++	
	Jenpeg operation	Reduced summer discharge		+++	
	"Deep-water" discharge	Reduced water quality		-?	
Cross Lake	Jenpeg road	Access	+++	+++	
	East Channel control	Access (if extended)	++	++	
	Jenpeg operation	Rising water levels	--		
	Jenpeg operation	Low summer levels	---	--	
Drunken Lake	Jenpeg road	Access	+++	+++	
	Jenpeg operation	Low summer levels	-	-	
Walker Lake	Jenpeg road	Access	+++	++	
	East Channel control	Access (if extended)	++	++	
	Jenpeg operation	Low summer levels	--	-	

Table 26. Predicted indices of total fish productivity, fishing opportunity, and productivity x opportunity, in the Lake Winnipeg Outlet Lakes area following hydro-electric development[a].

Regional component	Index of productive potential, years after development			Index of opportunity[b], years after development			Index of productivity x opportunity, years after development		
	5	15	50	5	15	50	5	15	50
Playgreen Lake	0.8	0.9	0.9	1.2	1.4	1.5	1.0	1.3	1.4
Little Playgreen Lake	1.1	1.1	1.1	1.3	1.4	1.4	1.4	1.5	1.5
East Channel	1.1	1.2	1.2	2+	2+	2+	2.2+	2.4+	2.4+
Pipestone Lake	0.8	0.7	0.7	1.5	1.8	2.0	1.2	1.3	1.4
Kiskittogisu Lake	1.5	2.5	2.0	1.5	1.8	2.0	2.2	4.5	4.0
Kiskitto Lake	1.5	3.0	3.0	1.5	1.8	2.0	2.2	5.4	6.0
West Channel(s)	1.2	1.1	1.0	2+	2+	2+	2.4+	2.2+	2.0+
Jenpeg forebay[c]	+	+++	+	2+	2+	2+	2+	2+	2+
Jenpeg tailrace[c]	++	+++	++	2+	2+	2+	2+	2+	2+
Cross Lake	1.0	0.9	0.9	1.2	1.5	1.8	1.2	1.4	1.6
Drunken Lake	0.8	0.7	0.7	1.3	1.4	1.5	1.0	1.0	1.1
Walker Lake	1.0	0.9	0.9	1.1	1.5	1.7	1.1	1.3	1.5

---

[a] No quantitative estimate of impact on the north Lake Winnipeg whitefish fishery is attempted; however there is some possibility of such an impact (see text).

[b] Maximum index assigned is 2. Where new access or development of new environment create completely new opportunity, this is indexed 2+.

[c] For these "new environment" components, with relatively no present productivity, anticipated productive potential has been rated as low (+), moderate (++), or high (+++).

average age at which the various species become vulnerable to fishing. At the other end of the time scale, it seems probable that about 50 years would be required for general stabilization of productivity impacts following hydro-electric development. Fish exploitation opportunity was indexed, intuitively, with attention to physical effects (new transportation corridors, hazards to boating and gillnetting, etc.), and to anticipated developments in marketing. An important assumption was that coarse fish species (notably suckers and ciscoes) will be generally marketable from these lakes sometime between 5-15 years after hydro development.

Future harvest potentials, as poundage of present "commercial" species available annually, were predicted from the recent annual harvests incorporating the indices of expected impact on productivity from Table 26. These predicted potentials are given in Table 27. A slight short-term (year 5) overall decline in harvest potential is anticipated, due mainly to a slight expected drop in productivity in Playgreen Lake. By year 15, however, harvest potentials for the present commercial species are expected to slightly exceed present yields, due mainly to expected increases in productivity in Kiskittogisu and Kiskitto Lakes. It is emphasized that future harvest capacity estimates on this basis adopted here follow the assumption that present yields represent present harvest capacities. As suggested in Section 6.7, however, present yields almost certainly underestimate present yield potentials of currently exploited species, perhaps by 2-3 times on average. This distinction has little significance in the present evaluation, however, because of the minor anticipated overall impact on productivity from hydro-electric development in the Outlet Lakes.

Table 27. Predicted annual fish harvest potentials in the Lake Winnipeg Outlet Lakes area following hydro-electric development. Estimates are on the basis of anticipated productive potentials only, i.e. excluding exploitation opportunity factors (see Table 26).

Regional component	Recent[a] annual harvest, cwt			Predicted harvest potential[c,d], cwt years after development		
	Commercial	Domestic[b]	Total	5	15	50
Playgreen Lake	3068	-	3068	2454	2761	2761
Little Playgreen Lake	0	1050	1050	1155	1155	1155
East Channel	0	-	0	+++	+++	+++
Pipestone Lake	78	-	78	62	55	55
Kiskittogisu Lake	191	-	191	287	478	382
Kiskitto Lake	163	-	163	245	489	489
West Channel(s)	0	0	0	++	++	++
Jenpeg forebay	0	0	0	++	++	++
Jenpeg tailrace	0	0	0	+++	+++	+++
Cross Lake	875	750	1625	1625	1463	1463
Drunken Lake	93	-	93	74	65	65
Walker Lake	756	-	756	756	680	680
Totals	5224	1800	7024	6658	7146	7050

[a] 1960-1971.

[b] Minimal estimate.

[c] On basis of (Recent annual harvest) x (Index of productive potential).

[d] For geographic components not exploited at present, important fishery potential is indicated ++, very important fishery potential is indicated +++.

Although indices of expected impact on fish exploitation opportunities were estimated, (Table 26), and composite (productivity) x (opportunity) indices were derived, little confidence is placed in the actual opportunity estimates. As a result, no formal attempt was made to incorporate the composite indices into estimates of fish harvest potentials. Most of the opportunity factors are positive, and involve either new access or creation of new fishery environment. Although relevant economic base date, marketing conditions, and past trends for the commercial fishery are available and were presented earlier in this report, a meaningful economic evaluation of fishery potentials and impacts would require sophisticated projections from these data regarding future price and cost factors for the commercial fishery, and also estimates of future sport-fishing demand. These projections have not been undertaken by the fisheries-limnology study sector.

7.3. Alternatives and mitigation:

The data base is generally too weak, the impacts too diverse, and the project too inflexible to permit development or meaningful evaluation of alternatives. However there are a few possible additions, deletions, or modifications to the proposed hydro works and operations which at least merit mention. These are developed briefly here and are also noted, as appropriate, under "Recommendations" (Section 8.1). Predicted effects of these modifications on fish productivity and fishery exploitation opportunities are indexed in Table 28. These indices can be related to actual anticipated harvest potentials by reference to Tables 26 and 27. Only such alternatives as appear fundamentally "reasonable" within the terms of reference of the study are considered. Not all benefits from the indicated alternatives are additive or independent.

Table 28. Predicted changes in index values for fish productive potentials and for fish exploitation opportunities which might attend mitigation measures in the Lake Winnipeg Outlet Lakes area. See Table 26 for index base values.

Regional component	Alternative or mitigation measure	Predicted change in index values			
		Productive potential, years after development			Exploitation opportunity
		5	15	50	
Playgreen Lake	None apparent	0.0	0.0	0.0	0.0
Little Playgreen Lake	None apparent	0.0	0.0	0.0	0.0
East Channel	Don't operate East Channel control	+0.2	+0.2	+0.2	0.0
East Channel	Provide fish passage in East Channel control	+0.2?	+0.2?	+0.2?	+0.2?
Pipestone Lake	Don't operate East Channel control	+0.2	+0.2	+0.2	0.0
Kiskittogisu Lake	Change channel route to avoid Kiskittogisu R.	+0.3	+0.3	+0.3	0.0
Kiskittogisu Lake	Clear areas to be flooded	-0.1	0.0	0.0	0.0
Kiskittogisu Lake	Eliminate dyking; curtail mechanized excavation[a]	-0.2	+0.1	+0.2	+0.2
Kiskittogisu Lake	Isolate dredge spoil; anchor peat deposits	+0.1	0.0	0.0	-0.1
Kiskitto Lake	Maintain 300 cfs discharge continuously[b]	+0.2	+0.1	+0.1	+0.1
West Channel	Don't improve Kisipachewuk Rapids	+0.1	+0.1	+0.1	0.0
Jenpeg forebay	Clear all areas to be flooded	-0.2	+0.1	0.0	-0.1
Jenpeg tailrace	None apparent	0.0	0.0	0.0	+1.0
Cross Lake	Control outlet to maintain summer levels	+0.2	+0.2	+0.2	0.0
Cross Lake	Improve outlet to accommodate winter flows	0.0	0.0	0.0	+0.4
Cross Lake	Forecast inflow to Lake Winnipeg and operate accordingly	0.0	0.0	0.0	+0.2
Cross Lake	Provide fish passage at Jenpeg	+0.1?	+0.1?	+0.1?	+0.1
Drunken Lake	Control Cross Lake outlet	+0.2	+0.2	+0.2	+0.1?
Drunken Lake	Control erosion on Black Duck Creek	+0.2	+0.1	+0.0	+0.4
Drunken Lake	Provide for fish passage at Minago crossing	+0.3?	+0.3?	+0.3?	0.0
Walker Lake	Control Cross Lake outlet	+0.1	+0.1	+0.1	+0.2

[a] This would also introduce some temporary disbenefits downstream, i.e. in Jenpeg forebay and in Cross Lake.

[b] This might cause disbenefits in Drunken Lake.

The most significant reasonable opportunity to enhance fish values in the Outlet Lakes area appears to be in reference to a control and, preferably, associated channel improvement, at the of Cross Lake. The purpose of such works would be to allow damp of the increased water level fluctuations otherwise predicted fo Lake, and to allow a more normal summer-winter water regime. Po downstream impacts (Duck Lake, Sipiwesk Lake, etc.), have not be sidered. In the same vein, some amelioration of abrupt changes charge to Cross Lake could probably be accomplished by developme application of seasonal runoff forecasts for the Lake Winnipeg d basin.

Fairly substantial fishery disbenefits could probably be av by not constructing or operating East Channel control. However for predictions is exceedingly weak. In any event, the benefits access to the area implicit in a control development outweigh an apparent disbenefits to fish productivity.

Complete clearing of the Jenpeg forebay area would probably little overall long-term impact on fish productivity, but would enhance the prospects for concerted exploitation. Prospects for mercial fishery are uncertain, but it is reasonably safe to assu none will develop within the 50-year time span being considered a great deal more clearing is done than is presently envisaged. thorough cut-and-leave program, with provision for subsequent ba and disposal of debris after flooding, could have important even benefits. Such an operation would probably be most effective in lower forebay area, where greatest reservoir depths would presum established. If a commercial fishery did develop in this area, program of gear compensation for damage and loss incurred by debris might legitimately be implemented.

The productivity of Kiskitto Lake could undoubtedly be increased by increased flow-through; however the magnitude of benefits cannot be predicted. In view of possible significant fishery disbenefits to Black Duck Creek and Drunken Lake, it is probably better to adopt a relatively conservative stance. However as much flexibility as possib should be incorporated into the Kiskitto inlet and outlet structures t allow future optimization of discharge and of regimes.

Meaningful alternatives regarding Kiskittogisu Lake have a high element of uncertainty regarding possible side effects. The one exception would be to change the course of the 8-mile channel to avoid Kiskittogisu River and its lagoons; however this seems scarcely feasib It has been mentioned (above) that long-term fishery interests might best be served by undertaking to stabilize the new shorelines as quick as possible. This could have very negative short-term effects, but might be best (and least costly) over the long-term. However the measures involved (clearing of forest on areas to be flooded, cessatio of dyking, perhaps cessation of mechanized excavation) would, with the possible exception of forest clearing, probably be unacceptable for cosmetic reasons and possible downstream effects. Clearing would definitely improve the prospects for future gillnetting in the lake.

e

e.

8. RECOMMENDATIONS

The participation of Resource Management Branch personnel Federal Fisheries Service in development of these recommendati acknowledged.

8.1. Design, operations, and mitigations:

a) Conduct feasibility studies of control and associated c improvements at Cross Lake outlet(s), with a view to mitiga anticipated increases in water level fluctuations and expec reversal of the seasonal water regime.

b) Develop and apply a forecasting model for predicting La Winnipeg seasonal inflows so that discharge can be regulate greater foresight and reduced amplitude of fluctuations.

c) Revise cutting specifications and contracts for the Jen bay area so that occurrence of merchantable timber is no lo criterion for cutting. Complete clear-cutting and disposal recommended, to 2 feet above expected high-water line. If not feasible, concentrate clearing efforts on the downstrea the reservoir. Burning of standing forest might be incorpo a clearing tool for islands and other isolated pockets.

d) Recommendations concerning Kiskittogisu Lake and the 8- channel are contingent upon such conclusions as may be deve under recommendation 8.2e) below. If major modifications c cannot be justified in a comprehensive evaluation it is rec that:

i) forest cover be cut, piled, and burned on selected

be flooded, with preference for areas where erosional co
quences would be minimal (to be defined);

ii) dredge spoil be confined to as small an area as possible
unless it can be conclusively shown that the dredge spoi
will anchor peat material, in which case cover as much p
as possible;

iii) attention be directed to re-routing and salvaging as muc
possible of any fish reproductive habitat in the Kiskitt
River tributaries.

e) Provide a 72-inch culvert for water discharge from the West
into Kiskitto Lake. This culvert should be fully submerged so a
be operational in winter. Maintain an inflow of at least 200 cf
Kiskitto Lake year-round, and more preferably flows of at least
in winter. Maintain the level of Kiskitto Lake between 698 and
feet. Provide a variable-crest control structure in the outlet
accommodate the specified flows and elevations, and to provide a
flexibility option as possible without disproportionately prejud
downstream fishery values.

f) Construct a fish attraction and fish holding device at the J
installation. Operate this device for two years following start-
to determine the composition and abundance of any fish attempting
ascend the Nelson River West Channel. Evaluate the data to dete
if a permanent fish passage facility is warranted. If affirmati
construct such a device. Provision for construction of an adequ
facility must be incorporated in the initial design of the Jenpeg
installation.

g) In the event of East Channel control, enough water (tentativ
estimate 4,800 cfs) must be discharged to ensure flow at all tim
all downstream channels. During May-June somewhat higher and mor

constant flows (tentative estimate 10,000 cfs) should be

as an aid to fish reproduction (see also recommendation 8

h) Any control structure on the East Channel should have

for fish passage, or provision to determine the need for

and to install it if the need is demonstrated.

8.2. Future studies and monitoring:

a) Establish and operate sediment traps at key locations

and Kiskittogisu Lakes to obtain baseline data and to mon

sedimentation effects of:

- i) 8-mile channel construction;
- ii) 2-mile channel construction;
- iii) 2-mile channel operation.

b) Determine the fishery resource in East Channel(s) of

River, and estimate fishery flow requirements and timing.

c) Determine the profile characteristics of the Minago R

the connections between Cross Lake-Walker Lake, and Cross

Pipestone Lake, with a particular view to the implication

Cross Lake water levels on boat access opportunities.

d) Conduct a detailed limnology-fisheries study of Cross

adjoining waters, to be able to better assess the implica

forecast changed water regime.

e) Evaluate the possible benefits-disbenefits, including

consequences, of the following measures for Kiskittogisu

the 8-mile channel:

- i) clear-cut some or all areas to be inundated;
- ii) curtail dyking operations;
- iii) curtail mechanized excavation.

f) Conduct studies to more conclusively assess the nature and significance of present fish interchange between Lake Winnipeg and Playgreen Lake.

g) Obtain field data to accurately assess the contribution of certain tributaries, notably Kiskittogisu River and Black Duck Creek, to fish recruitment in the receiving lakes.

9. PERSONAL COMMUNICATIONS CITED

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APPENDIX A - Summary of chemical analyses for six stations in the Lake Winnipeg Outlet Lakes area. Values are means of individual determinations over the period July 26 to Dec. 11, 1972. Analyses were by the Analytical Laboratory, Environment Canada, Calgary, for Environmental Protection Branch, Manitoba Dept. Mines, Resources, and Environmental Management (M. Morelli, personal communication). Values are mg/liter unless otherwise indicated.

PARAMETER	WARREN LANDING	NORWAY HOUSE	KISIPACHEWUK RAPIDS	JENPEG	CROSS LAKE	EVE RAPIDS
No. of Samples	1	5	4	4	5	5
Turbidity	35	14.3	23.0	35.8	22	28
Colour	20	22	22	27	23	26
pH	7.5	8.0	8.0	8.0	8.1	8.1
Chloride	36	16.7	16.5	19.7	17.0	16.9
Copper	0.003	0.003	0.004	0.002	0.002	0.004
Fluoride	0.09	0.08	0.07	0.08	0.09	0.08
Iron	-	< 0.05	0.08	0.06	0.11	0.11
Lead	< 0.004	< 0.006	< 0.006	< 0.006	0.007	< 0.006
Manganese	0.017	< 0.008	< 0.007	< 0.006	< 0.005	< 0.006
Nitrogen, T.K. (N)	-	0.94	0.69	0.78	0.76	0.67
Nitrogen, inorg. (N)	0.32	0.19	0.30	0.19	0.80	0.48
Phosphorus, total (P)	0.043	0.031	0.025	0.036	0.034	0.035
Phosphorus, ortho (P)	< 0.003	< 0.003	0.005	< 0.003	0.004	0.003
Phosphorus, inorg. (P)	< 0.003	< 0.004	0.006	0.005	0.005	0.004
Potassium	4.8	2.2	2.1	2.2	2.3	2.2
Residue, non-filt. (105C)	25.2	11.8	15.6	21.1	8.6	21.8
Residue, fixed (550C)	18	8.1	10.5	16.0	6.6	15.4
Mercury, μg/l	0.13	0.18	0.12	0.08	< 0.07	0.09
Zinc	0.017	0.003	0.007	0.002	0.006	0.001
Sodium	24	15.5	16.1	18.0	16.1	16.3
Silica	0.8	1.3	1.0	1.2	1.3	1.2
Sulphate	28.1	26.4	28.2	27.4	27.9	30.1
Calcium	30.9	31.9	31.8	30.6	32.2	30.9
Hardness, total ($CaCO_3$)	125	119	121	119	121	122
Alkalinity, total ($CaCO_3$)	95	103	99	101	99	100
Spec. conduct., μmho/cm	317	312	315	316	308	318
Inorg. carbon, total	11	17	15	12	16	16
Organic carbon, total	8	14	14	12	11	13

APPENDIX B1 - Summary of historical commercial fish production, participation, and value to fishermen, Playgreen Lake, 1940-1971.[a,b]

PERIOD	YEARS OF RECORD/ FISHING	NO. LICENSES ISSUED SUMMER/WINTER	FISH PRODUCTION, HUNDRED WEIGHT										VALUE TO FISHERMEN, 000 $
			WHITEFISH	WALLEYE	PERCH	PIKE	SAUGER	CISCO	SUCKERS	STURGEON	GOLDEYE	TOTAL	
<1954 Total	14/6	596/0	3443	522	0	135	0	36	578	251	0	4965	59.0
Mean Annual		42.6/0.0	246	37	0	10	0	3	41	18	0	355	4.2
1954-1959 Total	6/6	523/92	8745	3217	106	1741	13	597	1040	176	0	15635	174.7[c]
Mean Annual		87.2/15.3	1458	536	18	290	2	100	173	29	0	2606	29.1 +
1960-1965 Total	6/6	485/0	6298	1777	25	2335	4	1183	2807	23	0	14452	182.8
Mean Annual		80.8/0.0	1050	296	4	389	1	197	468	4	0	2409	30.5
1966-1971 Total	6/6	323/0	11997	2541	90	3290	0	1722	2689	24	0	22353	544.9
Mean Annual		53.8/0	1999	424	15	548	0	287	448	4	0	3725	90.8
All Years Total	32/24	1927/92	30483	8057	221	7501	17	3538	7114	474	0	57405	961.4
Mean Annual		60.2/2.9	953	252	7	234	1	110	222	15	0	1794	30.0
1960-1971 Mean Annual Production, lb/acre			0.95	0.23	0.01	0.29	+	0.15	0.29	+	0.00	1.92	

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[a] Based on Manitoba Govt. records to 1968; Freshwater Fish Marketing Corporation records for 1969, 1970, and 1971.

[b] Mean annual derivations are based on the number of years in the period (ie. years of record) rather than on number of years actually fished.

[c] Values for summer fishery only (87% of fish volume).

APPENDIX B2 - Summary of historical commercial fish production, participation, and value to fishermen, Kiskittogisu Lake, 1941-1971.[a,b]

PERIOD	YEARS OF RECORD/ FISHING	NO. LICENSES ISSUED SUMMER/WINTER	Fish Production, hundred weight										VALUE TO FISHERMEN, 000 $
			WHITEFISH	WALLEYE	PERCH	PIKE	SAUGER	CISCO	SUCKERS	STURGEON	GOLDEYE	TOTAL	
< 1954 Total	13/4	41/0	717	20	0	1	0	0	1	0	0	739	8.1
Mean Annual		3.2/0.0	55	2	0	+	0	0	+	0	0	57	0.6
1954-1959 Total	6/4	27/2	486	539	1	21	28	0	0	0	0	1075	14.8
Mean Annual		4.5/0.3	81	90	+	3	5	0	0	0	0	179	2.5
1960-1965 Total	6/4	19/0	242	856	0	143	0	0	0	0	0	1241	18.3
Mean Annual		3.2/0.0	40	143	0	24	0	0	0	0	0	207	3.1
1966-1971 Total	6/3	13/2	211	683	0	156	0	0	0	0	0	1050	32.0
Mean Annual		2.2/0.3	35	114	0	26	0	0	0	0	0	175	5.3
All Years Total	31/15	100/4	1656	2098	1	321	28	0	1	0	0	4105	73.2
Mean Annual		3.2/0.1	53	68	+	10	1	0	+	0	0	132	2.4
1960-1971 Mean Annual Production lb/acre			0.06	0.21	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.31	

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[a] Based on Manitoba Govt. records to 1968; Freshwater Fish Marketing Corporation records for 1969, 1970, and 1971.

[b] Mean annual derivations are based on the number of years in the period (ie. years of record) rather than on number of years actually fished.

APPENDIX B3 - Summary of historical commercial fish production, participation, and value to fishermen, Kiskitto Lake, 1957-1971.[a,b]

PERIOD	YEARS OF RECORD/ FISHING	NO. LICENSES ISSUED SUMMER/WINTER	FISH PRODUCTION, HUNDRED WEIGHT WHITEFISH	WALLEYE	PERCH	PIKE	SAUGER	CISCO	SUCKERS	STURGEON	GOLDEYE	TOTAL	VALUE TO FISHERMEN, 000 $
1954-1959 Total	3/3	0/10	199	301	0	4	0	0	0	0	88	592	8.9
Mean Annual		0.0/3.3	67	100	0	1	0	0	0	0	29	197	3.0
1960-1965 Total	6/6	22/6	344	477	0	6	0	0	0	0	216	1043	23.3
Mean Annual		3.7/1.0	57	80	0	1	0	0	0	0	36	174	3.9
1966-1971 Total	6/6	10/6	262	373	0	209	0	0	0	0	74	918	19.2
Mean Annual		1.7/1.0	44	62	0	35	0	0	0	0	12	153	3.2
All Years Total	15/15	32/22	805	1151	0	219	0	0	0	0	378	2553	51.4
Mean Annual		2.1/1.5	54	77	0	14	0	0	0	0	25	170	3.4
1960-1971 Mean Annual Production, lb/acre			0.09	0.13	0.00	0.03	0.00	0.00	0.00	0.00	0.04	0.29	

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[a] Based on Manitoba Govt. records to 1968; Freshwater Fish Marketing Corporation records for 1969, 1970, and 1971.

[b] Mean annual derivations are based on the number of years in the period (ie. years of record) rather than on number of years actually fished.

APPENDIX B4 - Summary of historical commercial fish production, participation, and value to fishermen, Pipestone Lake, 1957-1971.[a,b]

PERIOD	YEARS OF RECORD/ FISHING	NO. LICENSES ISSUED SUMMER/WINTER	FISH PRODUCTION, HUNDRED WEIGHT										VALUE TO FISHERMEN, 000 $
			WHITEFISH	WALLEYE	PERCH	PIKE	SAUGER	CISCO	SUCKERS	STURGEON	GOLDEYE	TOTAL	
1954-1959 Total	3/3	0/15	88	154	0	32	0	0	0	0	0	274	3.8
Mean Annual		0/5.0	29	51	0	11	0	0	0	0	0	91	1.3
1960-1965 Total	6/2	7/0	358	57	0	33	0	0	0	0	2	450	6.2
Mean Annual		1.2/0.0	60	10	0	5	0	0	0	0	+	75	1.0
1966-1971 Total	6/4	+/0	311	98	0	68	0	0	0	0	5	482	9.3
Mean Annual		4.5/0.0	52	16	0	11	0	0	0	0	1	80	1.6
All Years Total	15/9	34/15	757	309	0	133	0	0	0	0	7	1206	19.3
Mean Annual		2.3/1.0	50	21	0	9	0	0	0	0	+	80	1.3
1960-1971 Mean annual production, lb/acre			0.50	0.11	0.00	0.07	0.00	0.00	0.00	0.00	0.01	0.69	

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[a] Based on Manitoba Govt. records to 1968; Freshwater Fish Marketing Corporation records for 1969, 1970, and 1971.

[b] Mean annual derivations are based on the number of years in the period (i.e. years of record) rather than on number of years actually fished.

APPENDIX B5 - Summary of historical commercial fish production, participation, and value to fishermen, Cross Lake, 1959-1971.[a,b]

PERIOD	YEARS OF RECORD/ FISHING	NO. LICENSES ISSUED SUMMER/WINTER	FISH PRODUCTION, HUNDRED WEIGHT										VALUE TO FISHERMEN 000 $
			WHITEFISH	WALLEYE	PERCH	PIKE	SAUGER	CISCO	SUCKERS	STURGEON	GOLDEYE	TOTAL	
1954-1959 Total	1/1	0/12	672	44	0	61	0	6	0	0	1	784	10.0
Mean Annual		0.0/12.0	672	44	0	61	0	6	0	0	1	784	10.0
1960-1965 Total	6/6	62/26	4677	171	0	78	0	0	0	0	0	4926	80.2
Mean Annual		10.3/4.3	780	28	0	13	0	0	0	0	0	821	13.4
1966-1971 Total	6/6	91/0	4238	1194	0	143	0	0	0	0	0	5575	137.8
Mean Annual		15.2/0.0	706	199	0	24	0	0	0	0	0	929	23.0
All Years Total	13/13	153/38	9587	1409	0	282	0	6	0	0	1	11285	228.0
Mean Annual		11.8/2.9	737	108	0	22	0	1	0	0	+	868	17.5
1960-1971 Mean annual production, lb/acre			0.57	0.09	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.67	

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[a] Based on Manitoba Govt. records to 1968; Freshwater Fish Marketing Corporation records for 1969, 1970 and 1971.

[b] Mean annual derivations are based on the number of years in the period (ie. years of record) rather than on number of years actually fished.

APPENDIX B6 - Summary of historical commercial fish production, participation, and value to fishermen, Drunken Lake, 1960-1971.[a,b]

PERIOD	YEARS OF RECORD/ FISHING	NO. LICENSES ISSUED SUMMER/WINTER	FISH PRODUCTION, HUNDRED WEIGHT										VALUE TO FISHERMEN, 000 $
			WHITEFISH	WALLEYE	PERCH	PIKE	SAUGER	CISCO	SUCKERS	STURGEON	GOLDEYE	TOTAL	
1960-1965 Total	6/5	4/8	102	168	0	73	0	0	0	0	1	344	9.3
Mean Annual		0.7/1.3	17	28	0	12	0	0	0	0	+	57	1.6
1966-1971 Total	6/6	6/10	57	484	1	212	0	0	0	0	15	769	23.4
Mean Annual		1.0/1.7	10	81	+	35	0	0	0	0	2	128	3.9
All Years Total	12/11	10/18	159	652	1	285	0	0	0	0	16	1113	32.7
Mean Annual		0.8/1.5	13	55	+	24	0	0	0	0	1	93	2.7
1960-1971 Mean annual production, lb/acre			0.49	2.01	+	0.88	0.00	0.00	0.00	0.00	0.05	3.43	

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[a] Based on Manitoba Govt. records to 1968; Freshwater Fish Marketing Corporation records for 1969, 1970, and 1971.

[b] Mean annual derivations are based on the number of years in the period (ie. years of record) rather than on number of years actually fished.

APPENDIX B7 - Summary of historical commercial fish production and value to fishermen, Walker Lake, 1942-1971.[a,b]

PERIOD	YEARS OF RECORD/ FISHING	NO. LICENSES ISSUED SUMMER/WINTER	FISH PRODUCTION, HUNDRED WEIGHT										VALUE TO FISHERMEN 000 $
			WHITEFISH	WALLEYE	PERCH	PIKE	SAUGER	CISCO	SUCKERS	STURGEON	GOLDEYE	TOTAL	
<1954 Total	12/12	0/260	15413	2356	0	222	0	5	0	0	0	17996	141.9
Mean Annual		0.0/21.7	1284	196	0	19	0	1	0	0	0	1500	11.8
1954-1959 Total	6/6	24/47	4454	811	0	26	0	0	0	0	0	5291	52.6
Mean Annual		4.0/7.8	743	135	0	4	0	0	0	0	0	882	8.8
1960 - 1965 Total	6/5	78/20	2595	1990	0	131	0	0	0	0	0	4716	54.1
Mean Annual		13.0/3.3	432	332	0	22	0	0	0	0	0	786	9.0
1966-1971 Total	6/6	73/7	2967	1101	0	282	0	0	0	0	0	4350	110.6
Mean Annual		12.2/1.2	494	184	0	47	0	0	0	0	0	725	18.4
All Years Total	30/29	175/334	25429	6258	0	661	0	5	0	0	0	32353	359.2
Mean Annual		5.8/11.1	848	209	0	22	0	+	0	0	0	1079	12.0
1960-1971 Mean annual production, lb/acre			1.64	0.91	0.00	0.12	0.00	+	0.00	0.00	0.00	2.67	

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[a] Based on Manitoba Govt. records to 1968; Freshwater Fish Marketing Corporations records for 1969, 1970, and 1971.

[b] Mean annual derivations are based on the number of years in the period (ie. years of record) rather than on number of years actually fished.

APPENDIX C.

Province of Manitoba
Department of Mines, Resources and Environmental Management
Field Administration
P.O. Box 990
The Pas, Manitoba
R9A 1K9

Norway House, Manitoba.
February 13, 1973.

Gordon D. Koshinsky,
Lake Winnipeg, Churchill, Nelson River Study,
Fisheries Research Board of Canada,
501 University Crescent, Winnipeg.

Dear Sir:

I was successful in locating Gilbert Clarke, who traps around the south end of Kiskittogisu Lake, this morning.

When questioned about Jackfish spawning in the lagoons and creeks at the south end of Kiskittogisu Lake he informed me that this specie was very numerous at that location. He also volunteered the information that Pickerel frequented this particular area in large numbers during the spring spawning run.

I have no reason to doubt Mr. Clarke's word and it would therefore appear that the lagoons and creeks at the south end of Kiskittogisu Lake constitute a major spawning ground for Pickerel and Jackfish.

Yours Very Truly:

D.G.M.Allen

D.G.M.Allen
Snr. Conservation Officer
Norway House Settlement.

FRESHWATER INSTITUTE
ENVIRONMENT FISHERIES SERVICE
WINNIPEG, MAN.
FEB 15 1972
F.R.B.

APPENDIX D - Freshwater Fish Marketing Corporation initial fish prices to fishermen, F.O.B. Winnipeg receiving station, for the period May 1969 to October 1972. All prices are cents per pound.

SPECIES AND CATEGORY	SIZE	May 28 1969		Oct. 1 1970			May 1 1971		Oct. 15 1971			May 1 1972		Oct. 1 1972		
		Premium	Standard	Premium	Standard	Frozen	Premium	Standard	Premium	Standard	Frozen	Premium	Standard	Premium	Standard	Frozen
Whitefish	Jumbo (over 4 lb)	47	45	45	42	27	46	43	43	40	26	42	39	43	40	26
Export	Large (3-4 lb)	37	35	38	35	23	38	35	37	34	22	36	33	37	34	22
Dressed	Med. (1½ - 3 lb.)	24	22	30	27	17	28	25	28	25	16	29	26	29	26	17
	Small (1 - 1½ lb.)	14	12	11	11	7	-	12	11	11	7	-	12	-	12	8
Whitefish	Jumbo	10	10	37	34	22	34	31	37	34	22	32	29	37	34	22
Continental	Large	10	10	29	26	17	29	26	29	26	17	29	26	29	26	17
Dressed	Medium	10	10	24	21	13	24	21	23	20	13	25	22	24	21	14
	Small	10	10	8	8	5	-	9	9	9	6	-	10	-	10	7
Whitefish	Med. (1 3/4-3 lb)	47	45	-	-	-	-	40	-	-	-	-	37	-	34	-
Suckers Dressed	Small (1 - 13/4 lb)	28	26	-	-	-	-	13	-	-	-	-	12	-	-	-
Whitefish Cutters		-	-	-	-	-	-	14	-	13	8	-	-	-	15	10
Walleye	Large (over 3 lb)	24	22	-	40	34	-	39	-	44	38	-	-	-	44	38
Round	Med. (1 ½ - 3 lb)	24	22	-	40	34	-	39	-	44	38	-	-	-	44	38
	Small (under 1 ½ lb)	19	17	-	35	39	-	34	-	39	33	-	-	-	39	33
Walleye	Large	-	-	-	-	-	-	47	-	52	-	-	-	-	52	-
Dressed	Medium	-	-	-	-	-	-	47	-	52	-	-	-	-	52	-
	Small	-	-	-	-	-	-	41	-	47	-	-	-	-	47	-

APPENDIX D - Cont'd

SPECIES AND CATEGORY	SIZE	May 28 1969		Oct. 1 1970			May 1 1971		Oct. 15 1971			May 1 1972		Oct. 1 1972		
		Premium	Standard	Premium	Standard	Frozen	Premium	Standard	Premium	Standard	Frozen	Premium	Standard	Premium	Standard	Frozen
Pickerel	Large (over 3 lb)	-	33	-	-	-	-	51	-	56	-	-	51	-	56	-
Headless-	Med. (1 ¼ - 3 lb)	-	33	-	-	-	-	51	-	56	-	-	51	-	56	-
dressed	Small (under 1 ¼ lb)	-	28	-	-	-	-	44	-	51	-	-	44	-	51	-
Saugers Round	Large (over 12")	-	22[a]	-	35	29[a]	-	44[b]	-	51	45	-	44	-	34	38
(L. Winnipeg)	Med. (10" - 12")	-	17	-	-	-	-	34	-	-	-	-	34	-	27	21
Saugers Round		-	-	-	-	-	-	34[c]	-	-	-	-	-	-	39	33
(L. Manitoba)	Large (over 12")	-	-	-	-	-	-	29	-	39	33	-	-	-	-	-
Northern pike	Large (4 - 9 lb)	-	-	-	15	-	-	16	-	14	-	-	14	-	14	-
Dressed head on	Med. (2 - 4 lb)	-	-	-	12	-	-	12	-	-	-	-	-	-	-	-
Northern pike	Small (3/4 - 1 ½ lb)	-	-	-	11	8	-	-	-	13	10	-	8	-	9	7
Headless-dressed	(1 ½ lb. + over)	-	10[d]	-	6	4	-	11	-	8	6	-	14	-	14	11
Lake trout	Under 4 lb.	-	-	-	32	24	-	24	-	35	26	-	24	-	30	21
Dressed	4 - 8 lb.	24	22	-	38	29	-	29	-	30	21	-	29	-	35	26
Lake trout headless - dressed	Over 8 lb.	-	-	-	31	22	-	29	-	28	19	-	29	-	28	19
Lake trout cutters		-	-	-	23	14	-	21	-	20	11	-	21	-	20	11
Perch	Med. (½ - 3/4 lb)	-	2½[e]	-	8	6	-	8	-	12	12	-	12	-	13	13
Round	Large (over 3/4 lb)	-	-	-	16	14	-	12	-	16	16	-	16	-	17	17

APPENDIX D - cont'd

SPECIES AND CATEGORY	SIZE	May 28 1969		Oct. 1 1970			May 1 1971		Oct. 15 1971			May 1 1972		Oct. 1 1972		
		Premium	Standard	Premium	Standard	Frozen	Premium	Standard	Premium	Standard	Frozen	Premium	Standard	Premium	Standard	Frozen
Goldeye	Large (over 16 oz)	25	23	-	25	23	-	25	-	-	-	-	28	-	28	20
Dressed	Med. (12 - 16 oz)	16½	14½	-	20	18	-	20	-	-	-	-	18	-	18	15
	Small (6 - 12 oz)	-	-	-	10	-	-	07	-	-	-	-	5	-	13	10
Sturgeon	Over 12 lb.	-	-	-	-	-	1.50		-	-	-	1.50		-	-	-
Dressed	8 - 12 lb.	-	-	-	-	-	1.00		-	-	-	1.00		-	-	-
	6 - 8 lb.	-	-	-	-	-	0.50		-	-	-	.60		-	-	-
Tullibee	Large (over 1 ½ lb)	-	-	-	17	11	-	18	-	17	17	-	18	-	18	18
Export dressed	Med. (3/4 - 1 ½ lb)	-	-	-	12	8	-	13	-	12	12	-	13	-	13	13
Tullibee	Large	-	8	-	5	5	-	6	-	5	5	-	6	-	5	5
Contin Dressed	Medium	-	5	-	5	5	-	6	-	5	5	-	6	-	5	5
Mullets H.D.		-	-	-	4	-	-	4	-	4	3½	-	4½	-	8	-
Carp H.D.		-	-	-	3½	-	-	3	-	3	2½	-	-	-	3	-

[a] These prices for large (over 10") and small (7" - 10") with no lake indicated.

[b] Headless - dressed; large (over 10") and medium (8" - 10").

[c] Round; large (over 10") and medium (8" - 10").

[d] This price for all sizes, headless - dressed.

[e] All sizes.

APPENDIX E - Freshwater Fish Marketing Corporation prices for fish products, F.O.B. Canadian shipping point. Prices are in dollars per pound Canadian currency; price list issued July 10, 1972.

Species and category: size, product, etc.	Price per lb.			
A. FRESH FISH		Prem.	Std.	Cont.
Whitefish: Dressed (60 lb. pkg.)				
Jumbo (over 4 lb.)		.75	.75	.60
Large (3 - 4 lb.)		.70	.70	.50
Medium (1.5 - 3 lb.)		.55	.50	.45
Whitefish: Dressed and scaled				
Medium (1.5 - 3 lb.)		.64	.59	
Pan-ready		-	.75	
Fillets		-	1.29	
Walleye:		Rnd.	Drsd.	Hdls.
Large (over 3 lb.)		.80	.80	.85
Medium (1.5 - 3 lb.)		.80	.80	.85
Small (under 1.5 lb.)		.75	.75	.80
Small, headless, scaled	.88			
Medium, headless, scaled	.88			
Pan-ready	1.30			
Fillets, skin on	1.59			
Fillets, skinless	1.67			
Sauger: Headless, dressed				
Large, (over 10")	.75			
Medium (8" - 10")	.65			
Large, headless, scaled	.83			
Pan-ready	1.30			
Tullibee: Dressed		Prem.		Cont.
Large (over 1.5 lb.)		.35		.25
Medium (0.75 - 1.5 lb.)		.30		.23
Lake Trout:		Prem.	Std.	
Dressed, 4 - 8 lb.		.60	.55	
Dressed, under 4 lb.		.55	.50	
Headless-dressed		.50	.50	
Fillets, 6 - 10 oz., skin on			.98	
Pan-ready			.86	
Steaks, 6 - 10 oz.			.90	
Scaled, under 4 lb.			.60	

APPENDIX E - cont'd

Perch: Round	Std.
Large (over 0.75 lb.)	.45
Medium (under 0.75 lb.)	.35
Northern Pike:	
Dressed, head on, 4 - 9 lb.	.40
Dressed, head on, 2 - 4 lb.	.35
Headless - dressed	.30
Fillets, skinless	.70

APPENDIX E: Cont'd

Species and category: size, product, etc.	Price per lb.			
B. FROZEN FISH				
Whitefish: Dressed			Export	Cont.
Jumbo (over 4 lb.)			.65	.45
Large (3 - 4 lb.)			.55	.39
Medium (1.5 - 3 lb.)			.44	.33
Lake Trout: Dressed				
Over 4 lb.	.55			
Under 4 lb.	.44			
Headless	.53			
Walleye:		Rnd.	Drsd.	Hdls.
Large		.80	.80	.85
Medium		.80	.80	.85
Small		.75	.75	.80
Northern Pike: Dressed				
4 - 9 lb.	.37			
2 - 4 lb.	.31			
Headless	.28			
Tullibee: Dressed			Export	Cont.
Large			.29	.24
Medium			.28	.22
Ungraded			.22	
Perch: Round				
Large	.45			
Medium	.35			
Sauger: Headless, Lake Winnipeg				
Large	.75			
Medium	.65			

APPENDIX E: Cont'd

Species and category: size, product, etc.	Price per lb.
C. PROCESSED FISH:	
Whitefish:	
Boned banquet fillets	.95
Regular banquet fillets	.85
Pan-ready	.62 - .69
Tail section	.59 - .64
I.Q.F. tails	.88
Breaded raw boned fillets	.95
Breaded raw tails	.95
Cooked breaded boned fillets	.99
Walleye:	
Banquet fillets	1.52
Small, pan-ready	1.21
Raw breaded fillets	1.52
Cooked breaded fillets	1.57
Sauger:	
Large, pan-ready	1.21
Northern pike: banquet fillets	
Graded	.62
Pan-ready	.49
Lake trout: banquet fillets	
Graded	.74
Tail sections, bone in	.73 - .79
Steak	.93

12. MAPS

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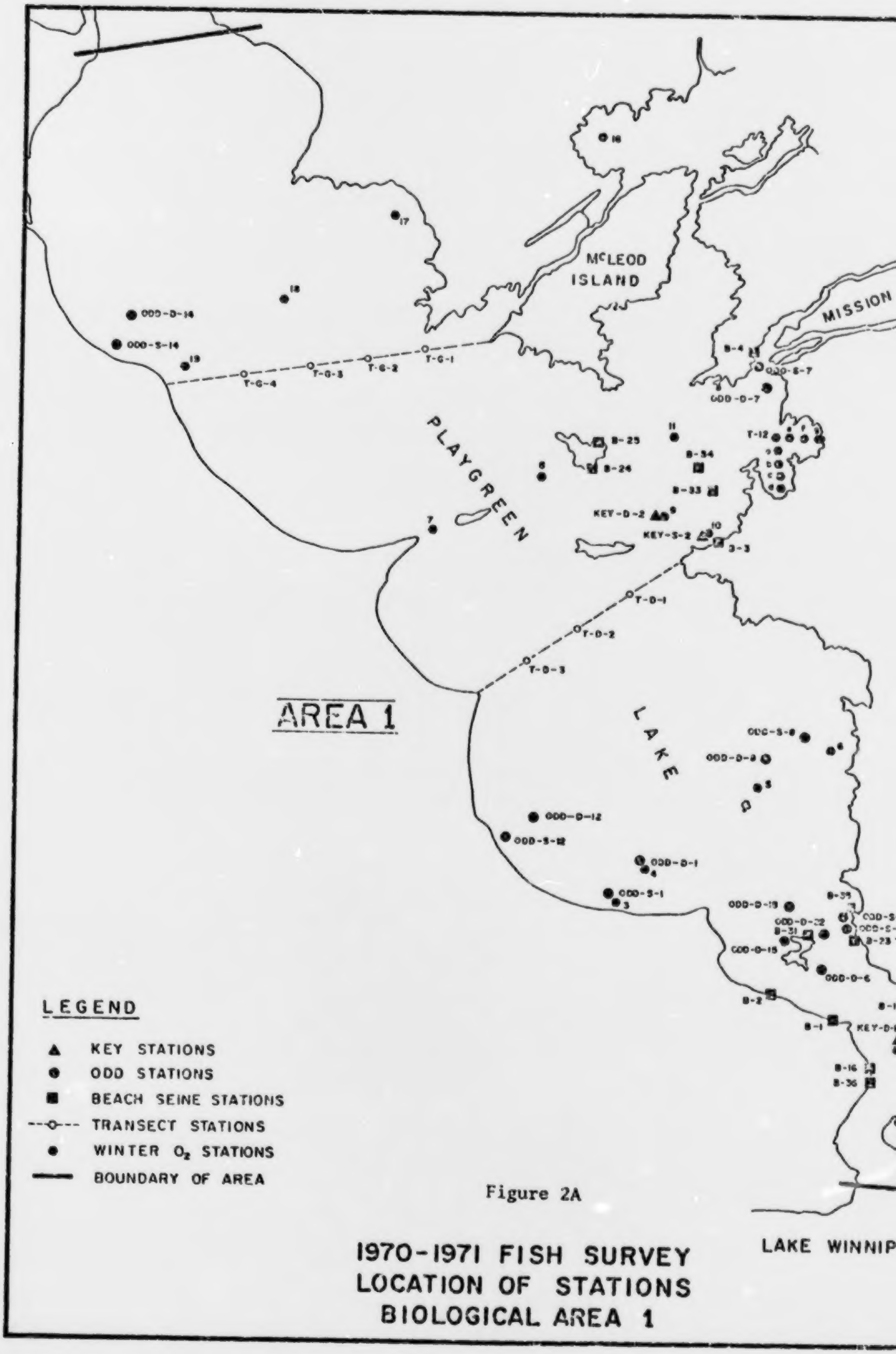
MᶜLEOD ISLAND
MISSION
PLAYGREEN
LAKE
AREA 1
LAKE WINNIP
ODD-D-14
ODD-S-14
16
17
18
19
T-G-1
T-G-2
T-G-3
T-G-4
B-4
ODD-S-7
ODD-D-7
T-12
11
B-25
B-24
B-34
B-33
8
7
KEY-D-2
KEY-S-2
10
B-3
T-D-1
T-D-2
T-D-3
ODC-S-8
ODD-D-8
5
6
ODD-D-12
ODD-S-12
ODD-D-1
4
ODD-S-1
3
ODD-D-13
B-35
ODD-D-22
B-31
ODD-D-15
B-23
ODD-D-6
B-2
B-1
KEY-D
B-16
B-36
LEGEND
▲ KEY STATIONS
● ODD STATIONS
■ BEACH SEINE STATIONS
--o-- TRANSECT STATIONS
• WINTER O_2 STATIONS
— BOUNDARY OF AREA

Figure 2A

1970-1971 FISH SURVEY
LOCATION OF STATIONS
BIOLOGICAL AREA 1

ISLAND
B-15 & B-22
KEY-S-1
B-17
URVIS
SLAND
G

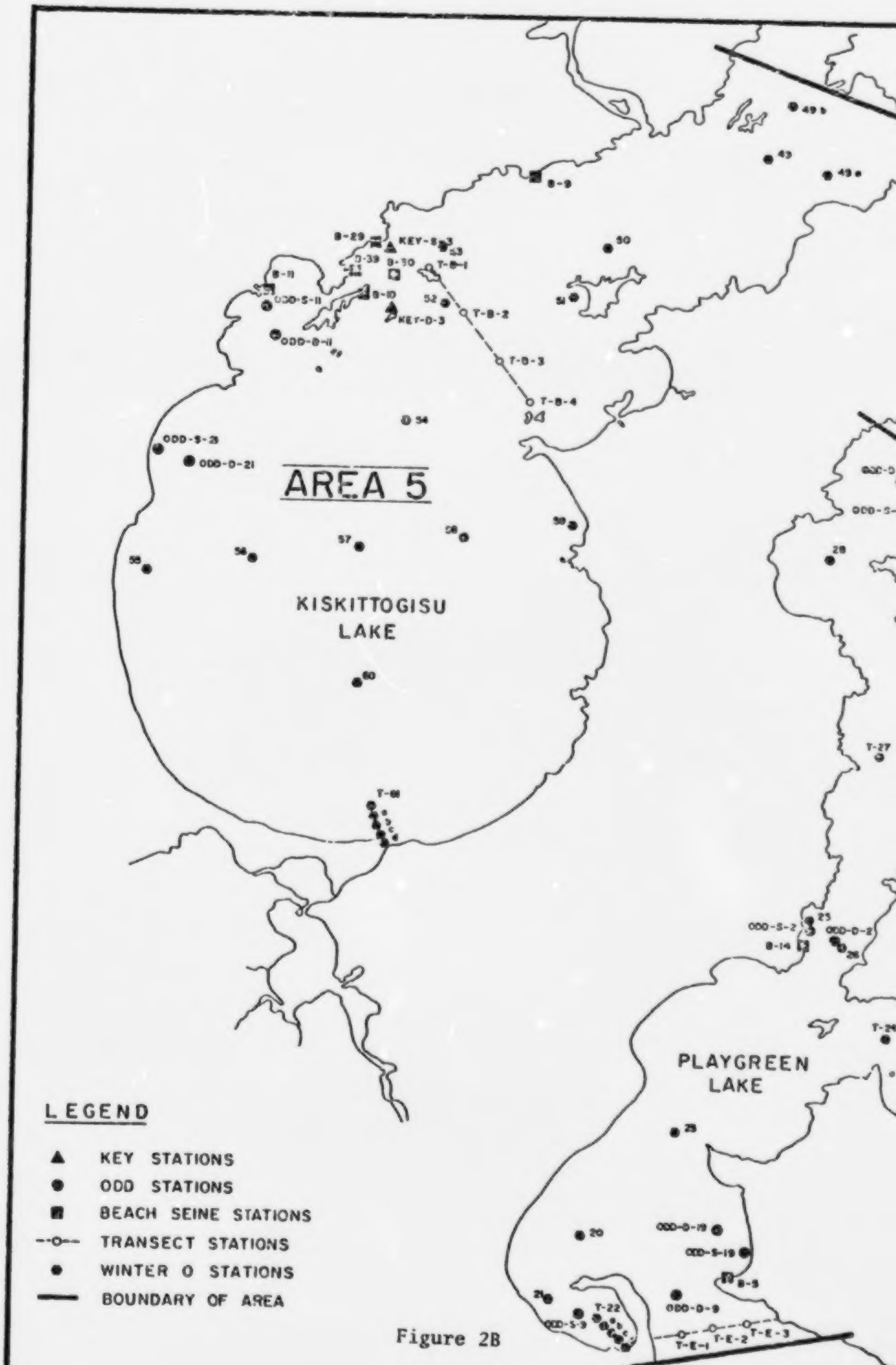
AREA 5
KISKITTOGISU LAKE
PLAYGREEN LAKE
KEY-S-3
KEY-D-3
B-9
B-10
B-11
B-14
B-29
B-30
B-39
T-B-1
T-B-2
T-B-3
T-B-4
ODD-S-11
ODD-D-11
ODD-S-21
ODD-D-21
ODD-S-2
ODD-D-2
ODD-D-19
ODD-S-19
ODD-D-9
ODD-S-3
T-22
T-27
T-60
T-E-1
T-E-2
T-E-3
LEGEND
▲ KEY STATIONS
● ODD STATIONS
■ BEACH SEINE STATIONS
--○-- TRANSECT STATIONS
• WINTER O STATIONS
— BOUNDARY OF AREA

Figure 2B

1970-1971 FISH SURVEY
LOCATION OF STATIONS
BIOLOGICAL AREAS 2 & 5

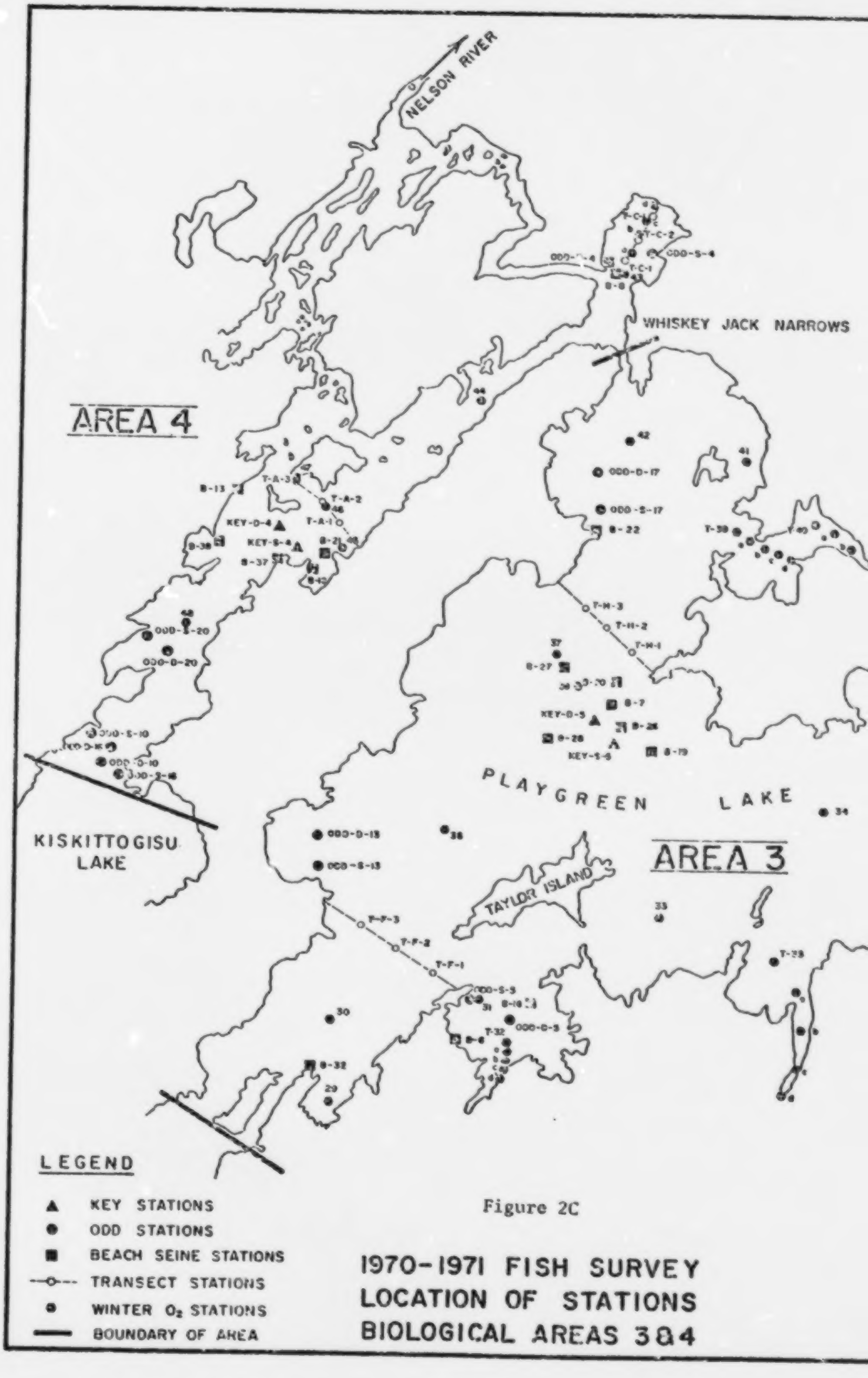
NELSON RIVER
WHISKEY JACK NARROWS
AREA 4
AREA 3
KISKITTOGISU LAKE
PLAYGREEN LAKE
TAYLOR ISLAND
ODD-S-4
T-C-1
T-C-2
B-13
T-A-3
T-A-2
T-A-1
KEY-D-4
KEY-S-4
B-38
B-37
B-21
ODD-D-20
ODD-S-10
ODD-D-10
ODD-D-17
ODD-S-17
B-22
T-39
T-40
T-H-3
T-H-2
T-H-1
B-27
B-7
KEY-D-5
B-26
B-28
KEY-S-5
B-19
ODD-D-13
ODD-S-13
T-F-3
T-F-2
T-F-1
ODD-S-3
ODD-D-3
T-32
B-32
T-29
LEGEND
▲ KEY STATIONS
● ODD STATIONS
■ BEACH SEINE STATIONS
--○-- TRANSECT STATIONS
● WINTER O_2 STATIONS
— BOUNDARY OF AREA

Figure 2C

1970-1971 FISH SURVEY
LOCATION OF STATIONS
BIOLOGICAL AREAS 3&4

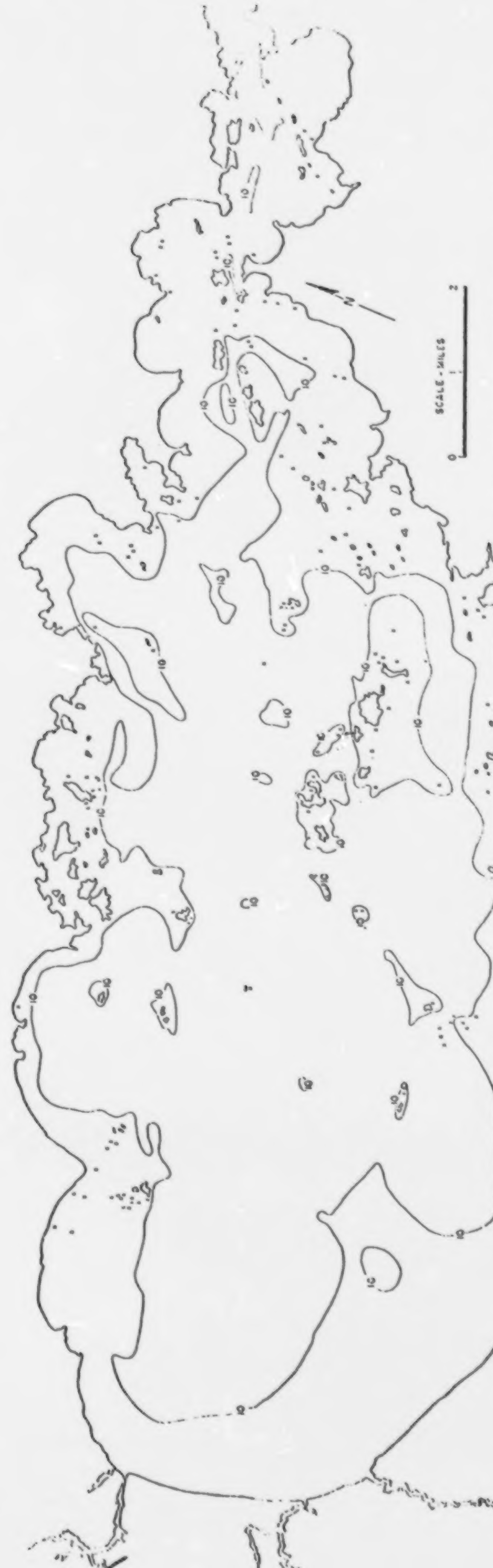
10
N
SCALE - MILES
0
1
2

Figure 5. Contour map of [illegible] Lake [illegible] by A. [illegible] (personal communication, [illegible])

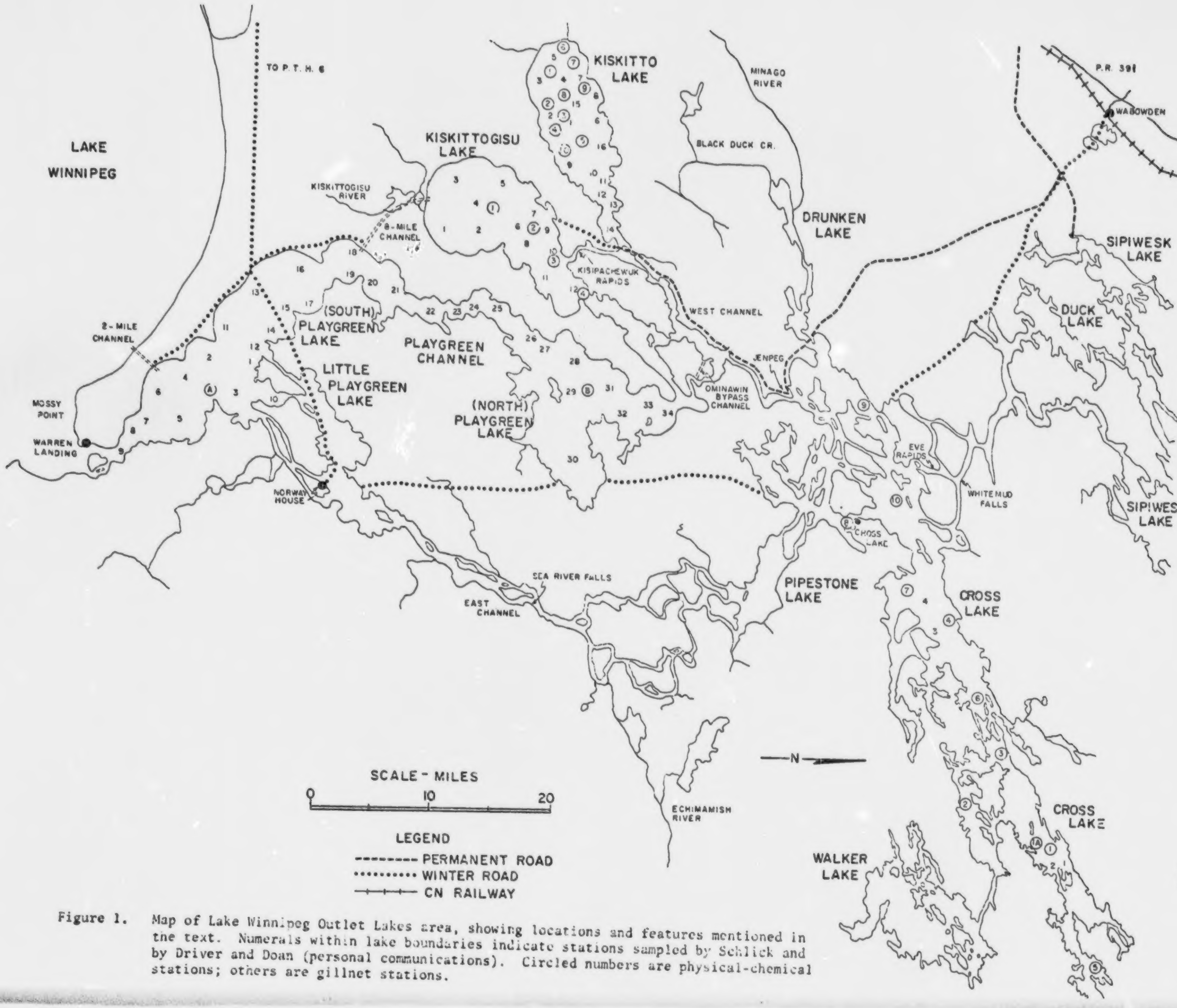
LAKE WINNIPEG
TO P.T.H. 6
KISKITTOGISU RIVER
8-MILE CHANNEL
KISKITTOGISU LAKE
KISKITTO LAKE
MINAGO RIVER
BLACK DUCK CR.
DRUNKEN LAKE
P.R. 391
WABOWDEN
SIPIWESK LAKE
DUCK LAKE
2-MILE CHANNEL
MOSSY POINT
WARREN LANDING
(SOUTH) PLAYGREEN LAKE
PLAYGREEN CHANNEL
LITTLE PLAYGREEN LAKE
(NORTH) PLAYGREEN LAKE
KISIPACHEWUK RAPIDS
WEST CHANNEL
JENPEG
OMINAWIN BYPASS CHANNEL
NORWAY HOUSE
EYE RAPIDS
WHITEMUD FALLS
SIPIWESK LAKE
CROSS LAKE
SEA RIVER FALLS
EAST CHANNEL
PIPESTONE LAKE
CROSS LAKE
N
SCALE - MILES
0
10
20
ECHIMAMISH RIVER
CROSS LAKE
WALKER LAKE
LEGEND
PERMANENT ROAD
WINTER ROAD
CN RAILWAY

Figure 1. Map of Lake Winnipeg Outlet Lakes area, showing locations and features mentioned in the text. Numerals within lake boundaries indicate stations sampled by Schlick and by Driver and Doan (personal communications). Circled numbers are physical-chemical stations; others are gillnet stations.

APPENDIX 5 - VOL. 2 - B

THE FISHERIES OF THE EAST CHANNEL OF THE NELSON RIVER

THE FISHERIES OF THE EAST CHANNEL OF THE NELSON RIVER

by

H. A. AYLES
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
April, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

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ACKNOWLEDGMENTS

The author would like to acknowledge both B. Yake and D. Ramsey for their work in collecting the fisheries samples from the East Channel. B. Yake, in particular, had to interpret the vague requests for information, and managed to return with a successful sampling in the short period of time allotted.

Dr. R. Hecky took the time to critically review this report and his comments and suggestions were appreciated.

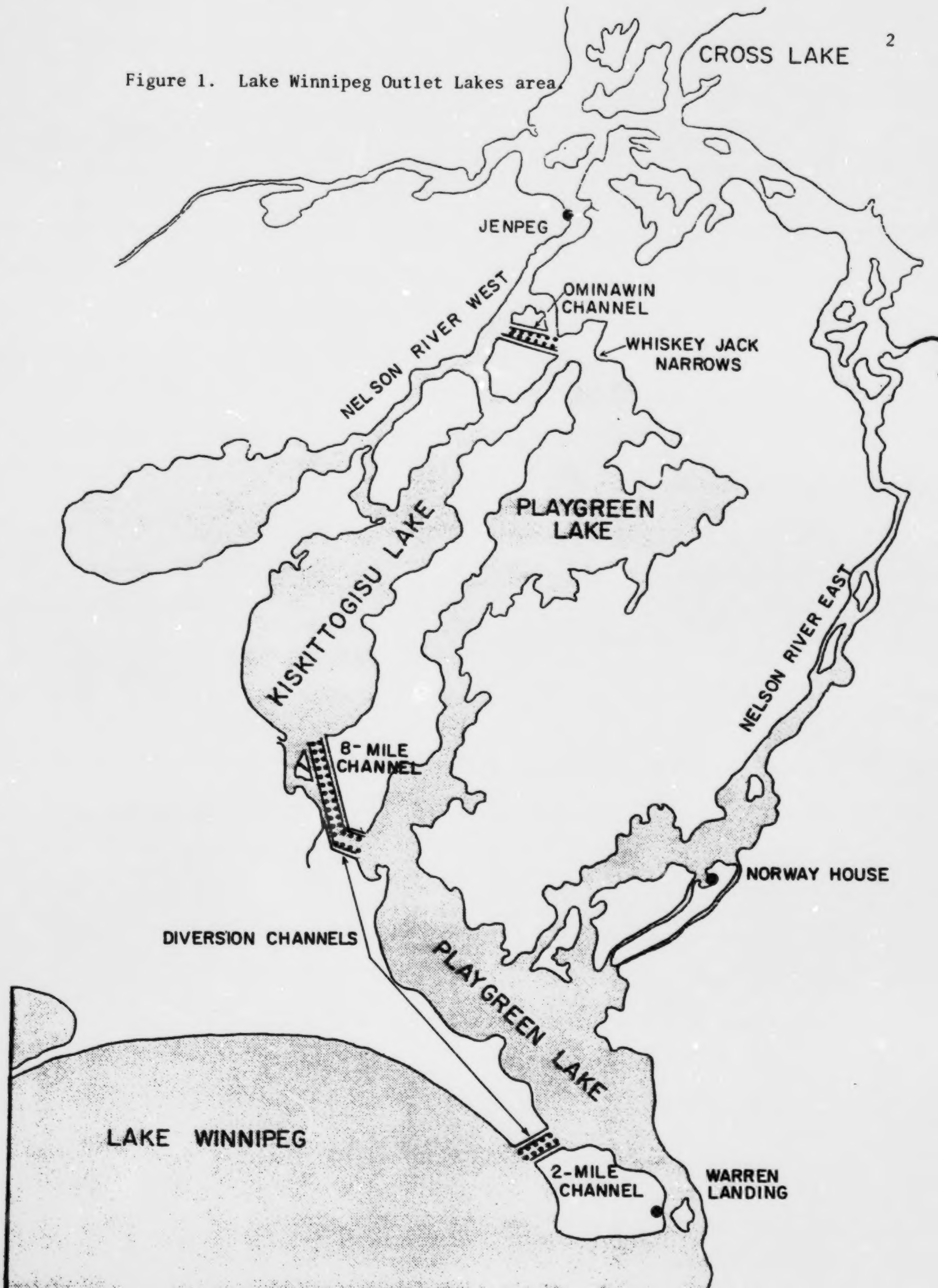
INTRODUCTION

Manitoba Hydro is in the process of developing the Nelson River for hydroelectric power. One portion of this development is the construction of the hydroelectric generating station on the West Channel of the Nelson River and the subsequent regulation of water levels on Lake Winnipeg. Under natural conditions the West Channel receives between 80% and 85% of the total Nelson River flow, and the East Channel the remaining 15% to 20% (Fig. 1). To prevent the loss of up to 20% of the flow through the East Channel, Manitoba Hydro has been considering a control structure on the East Channel at Sea River Falls to reduce the flow through this channel particularly during the summer at times of low flow.

Under regulation, the average level of Lake Winnipeg will be increased approximately 1 foot, resulting in an increased flow in the present East Channel of from 15% to 20%. If a control structure were constructed on the East Channel, flows could be reduced from an average of 12,000 cfs to a minimum of 1,000 cfs. Such a facility could create an obstruction to fish passage along the East Channel, and a reduction in spawning success of some species of fish. For more particulars about proposed flows and conditions in the East Channel see "East Channel Hydraulic Study", a report prepared for the Lake Winnipeg, Churchill and Nelson Rivers Study by the provincial Water Resources Branch.

The fisheries-limnology component of the Lake Winnipeg, Churchill and Nelson Rivers Study agreed to investigate the existing fishery in the East Channel and provide information on the possible effects of a control structure on the fishery.

Figure 1. Lake Winnipeg Outlet Lakes area.


CROSS LAKE
JENPEG
NELSON RIVER WEST
OMINAWIN CHANNEL
WHISKEY JACK NARROWS
PLAYGREEN LAKE
KISKITTOGISU LAKE
NELSON RIVER EAST
8-MILE CHANNEL
NORWAY HOUSE
DIVERSION CHANNELS
PLAYGREEN LAKE
LAKE WINNIPEG
2-MILE CHANNEL
WARREN LANDING

SUMMARY

1. The results of a 10-day fisheries investigation on the East Channel are briefly described and are compared with results from fisheries investigations on Playgreen and Cross Lake.
2. The East Channel appears to have a species composition very similar to Cross and Playgreen Lakes, with the exception of fish species (e.g. whitefish) not normally found in riverine habitat.
3. There was a poor quantity of aquatic vegetation and of forage fish species along most of the shoreline of the East Channel.
4. The East Channel is not as productive as either Playgreen or Cross Lake which is not unexpected from a riverine habitat.
5. Growth rate of walleye from the East Channel was poorer than growth rate of walleye from either Playgreen or Cross, however walleye from the East Channel and Playgreen were similar in condition.
6. Northern pike from the East Channel were in similar condition to northern pike from Playgreen Lake, and in better condition than those from Cross. Pike from the Outlet Lakes appeared to be in better than average condition than pike from other northern systems.
7. There has been no commercial fishing in the East Channel in the past and it seems unlikely that it will become economically feasibl to commercially fish this area in the near future.
8. There have been no sports fishery facilities in the Lake Winnipeg Outlet Lakes area in the past and the sport fishing for walleye

and northern pike in the East Channel does not appear to be good enough under existing conditions to warrant any such facilities. However, the creation of a tail-race environment at a control structure at Sea River Falls may improve sport fishing considerab

9 A control structure would prevent movement of fish past Sea Rive Falls, however, from the investigations made on the East Channel it would appear that any such impairment of movement would not b of major biological importance.

10. Extreme reduction in flows through the East Channel to Pipestone would reduce the supply of nutrient rich Nelson River water hence reducing the productive capacity of Pipestone Lake.

11. The recommendations made are:

    a) Provide for a fish attraction device at the control structure to determine if the need exists for a fish passage facility.

    b) Maintain flows through the East Channel, during late spring and early summer, at a level of 10,000 cfs to ensure successf spawning and incubation of such species as walleye and northern pike.

    c) Maintain minimum flows to Pipestone Lake at the historic mean low levels (1,500 cfs instead of the proposed 1,000 cfs).

METHODS

Personnel from the Manitoba Department of Mines, Resou and Environmental Management took field samples from the East Cha during the period June 20 to June 29, 1973. Fish sampling consis of overnight gill net sets, minnow trap sets and angling with rod reel. The gill nets were "Swedish" nets which are monofilament n consisting of twelve combined mesh sizes ranging from 3/4" to 6" mesh), each 10 feet long. Set locations varied according to the conditions although most types of river habitat were sampled. Al captured had weights and fork lengths taken and a scale sample re Small fish species were preserved for laboratory identification.

A total of fourteen overnight gill net sets were made. To facilitate comparisons within the East Channel system, and betwee systems all lengths of sets were mathematically adjusted to sixte hours, and catch per unit effort values were mathematically adjus compensate for the short length of the "Swedish" gill nets.

To determine age of fish taken from the East Channel the n of true annuli or rings on the fish scale was considered to be th as the true age. Scales were read by one person although the sam did not read scales taken on Cross and Playgreen Lakes. Although scales were not "key" scales, i.e. the same scale removed from ea specimen, they were removed from the same area on each species.

To facilitate comparisons of condition of the fish with th reported in the literature, units of length and weight were conve to metric measurement and appear in the report in this form.

Data from the East Channel have been compared to data from Playgreen Lake and Cross Lake. The data from Playgreen Lake have been taken from Koshinsky (1973) and Ayles (1973) and those from Cross Lake appear in Koshinsky (1973).

SPECIES COMPOSITION

Fish species taken from the East Channel in 1973 are listed Table 1. The list is quite sparse which undoubtedly reflects the short period of time spent in the field. However, according fisheries personnel involved in the field sampling, areas of good s line habitat were scarce, and few observations of forage fish were

Whitefish were not taken from the East Channel, which is not unexpected as they are normally found only in a lake habitat. Alth walleye were taken in the experimental nets, sauger were not. Thi perhaps be explained by a greater tolerance of the walleye to flow water than the sauger. Sauger were never taken in large numbers f Playgreen and Cross Lakes (Koshinsky, 1973) and it may be that the northern latitude as well as the riverine habitat are enough to pr establishment of this species in the East Channel.

The East Channel appears to have a closer similarity of fis species to Cross Lake, than to Playgreen Lake. This is most likel result of inadequate sampling from Playgreen Lake rather than a s of actual differences between these bodies of water. The East Ch Playgreen Lake and Cross Lake probably have a similar fish fauna species intolerant to riverine habitats being absent from the Eas Channel.

Table 1. Known occurrence of fish species in Cross Lake, Playgreen Lake and the East Channel.

		East Channel	Playgreen	Cross
Lake whitefish	*Coregonus clupeaformis*		x	x
Walleye	*Stizostedion vitreum*	x	x	x
Sauger	*Stizostedion canadense*		x	x
Cisco	*Coregonus* sp.	x	x	x
Burbot	*Lota lota*	x	x	x
Northern pike	*Esox lucius*	x	x	x
Yellow perch	*Perca flavescens*	x	x	x
Trout-perch	*Percopsis omiscomaycus*	x		
Longnose sucker	*Catostomus catostomus*	x	x	x
White sucker	*Catostomus commersoni*	x	x	x
Shorthead redhorse	*Moxostoma macrolepidotum*	x	x	x
Goldeye	*Hiodon alosoides*			x
Mooneye	*Hiodon tergisus*	x		x
Lake sturgeon	*Acipenser fulvescens*		x	x
Brook stickleback	*Culaea inconstans*			x
Ninespine stickleback	*Pungitius pungitius*			x
Fathead minnow	*Pimephales promelas*			x
Lake chub	*Couesius plumbeus*			x
Longnose dace	*Rhinichthys cataractae*			x
Mottled sculpin	*Cottus bairdi*	x		x
Slimy sculpin	*Cottus cognatus*	x		x
Iowa darter	*Etheostoma exile*			x
Johnny darter	*Etheostoma nigrum*			x
Emerald shiner	*Notropis atherinoides*			x
Spottail shiner	*Notropis hudsonius*	x		x
Blacknose shiner	*Notropis heterolepis*			x

Catch per unit effort, growth and condition

The quality and quantity of the catch varied according to the location of the gill net sets (Fig. 2). Northern pike were taken in greatest quantities from the mouth of the East Channel in Pipestone Lake, while shorthead redhorse suckers were taken only from the more riverine habitat.

Although it is difficult to compare catch records between lakes with a high degree of confidence an attempt has been made to equalize the conditions (i.e. length of gill nets) to allow at least a general comparison (Table 2).

It would appear that, in number, the East Channel is only one half as productive as Playgreen Lake and about one third as productive as Cross Lake. A great deal of the difference in standing crop exists in the absence of whitefish, the scarcity of cisco, and the poor sample of northern pike from the East Channel. As well, much of the discrepancy can probably be explained by the fact that the East Channel, with its strong current, exhibits the productive capacity of a river habitat, rather than a lake habit as found in Playgreen and Cross Lake. In the riverine situation a strong current and the related turbidity produces a high dilution rate and an unfavourable light climate which can inhibit primary production in even nutrient-rich water. Numbers of walleye taken in the experimental gill nets in the East Channel exceeded numbers of walleye taken experimentally in Playgreen Lake however they did not exceed numbers taken from Cross Lake (Table 2). Although it is possible that a high yield of walleye in the East Channel could be the result of spawning adults from Pipestone Lake, this seems unlikely in this case when only 17% of the sample could have been mature (6+ years).

Lengths at age of walleye from the three locations (Table 3) indicate that walleye from Playgreen Lake had the most rapid rate of growth, and walleye from the East Channel the poorest. This is not unusual when it is considered that the habitat available to walleye in Playgreen, and even Cross Lake, is superior to what is available in the East Channel.

Condition of walleye from the East Channel and Playgreen Lake is similar and walleye from both are in significantly better condition than walleye from Cross Lake (Fig. 4). The mean length of walleye from the East Channel is less than the mean length of walleye from either Playgreen or Cross Lake. It would appear, then, that the walleye in the East Channel do not grow as quickly as walleye from nearby lakes, but for their length they are in relatively good condition.

Catch per unit effort (numbers) and mean length for pike from the experimental gill nets were surprisingly low particularly considering that 90% of the creel was comprised of this species (10% walleye). Apparently the ability of the monofilament net to hold the larger sized pike was poor and as the gang of nets was lifted many larger pike were observed escaping (B. Yake pers. comm.). Therefore, for the purpose of this discussion, only pike condition has been considered when comparing pike from the East Channel with those from other bodies of water.

According to the condition regressions (Fig. 5) northern pike from the East Channel are in better condition, for their age, than northern pike from Cross, and they are not significantly different from northern pike from Playgreen Lake. Condition factors for pike from these areas (East Channel, 0.89; Playgreen, 0.76; Cross, 0.70) support these observations;

however, the value for the East Channel may be excessively high because of the low mean age of the fish sampled. The condition factors for pike from these three areas compare more than favourably with condition factors of northern pike from a variety of locations in North America (Carlander, 1969) suggesting that pike from this water system may be in better than average condition.

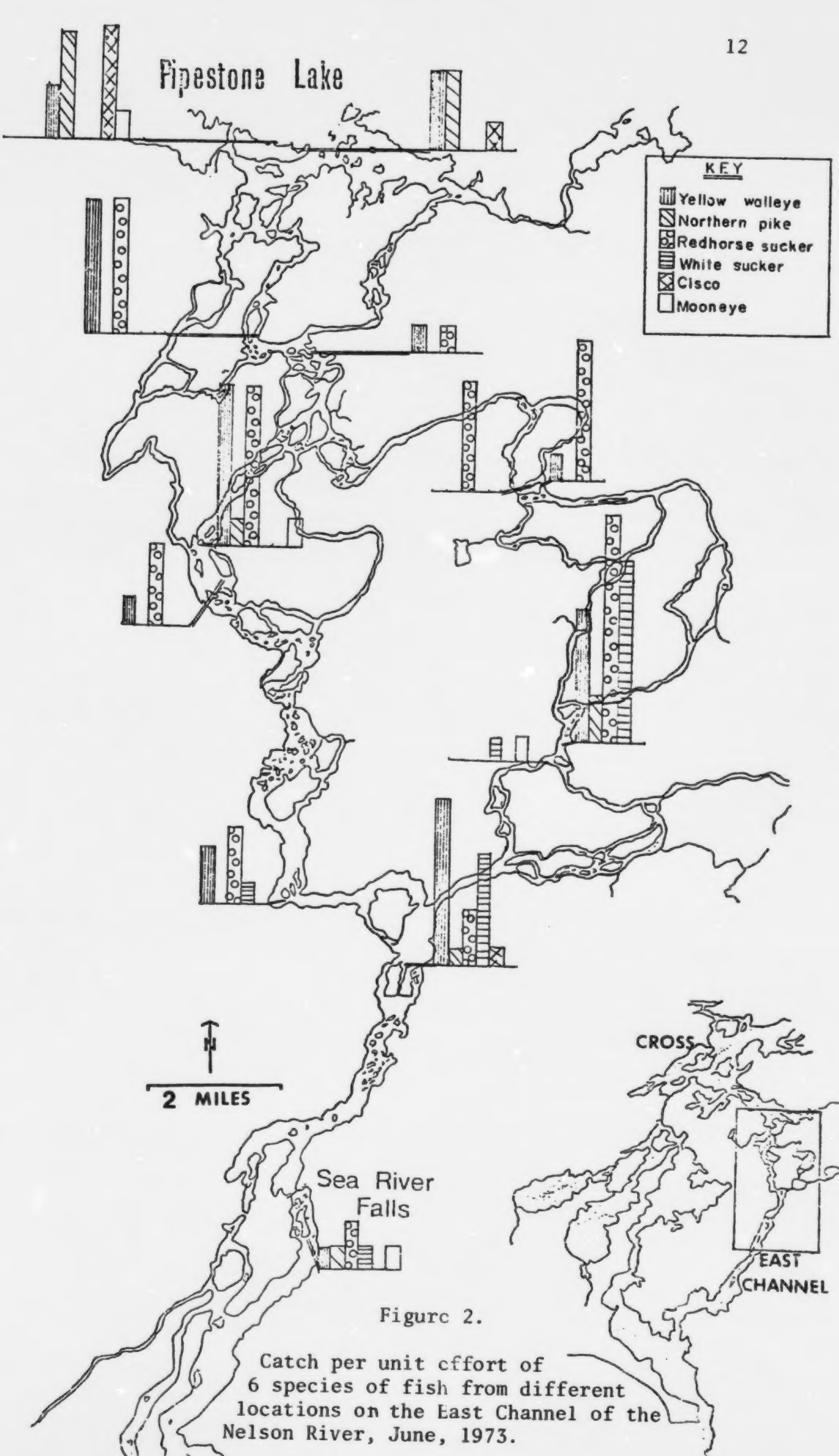

Fipestone Lake
KEY
Yellow walleye
Northern pike
Redhorse sucker
White sucker
Cisco
Mooneye
N
2 MILES
Sea River Falls
CROSS
EAST CHANNEL

Figure 2.

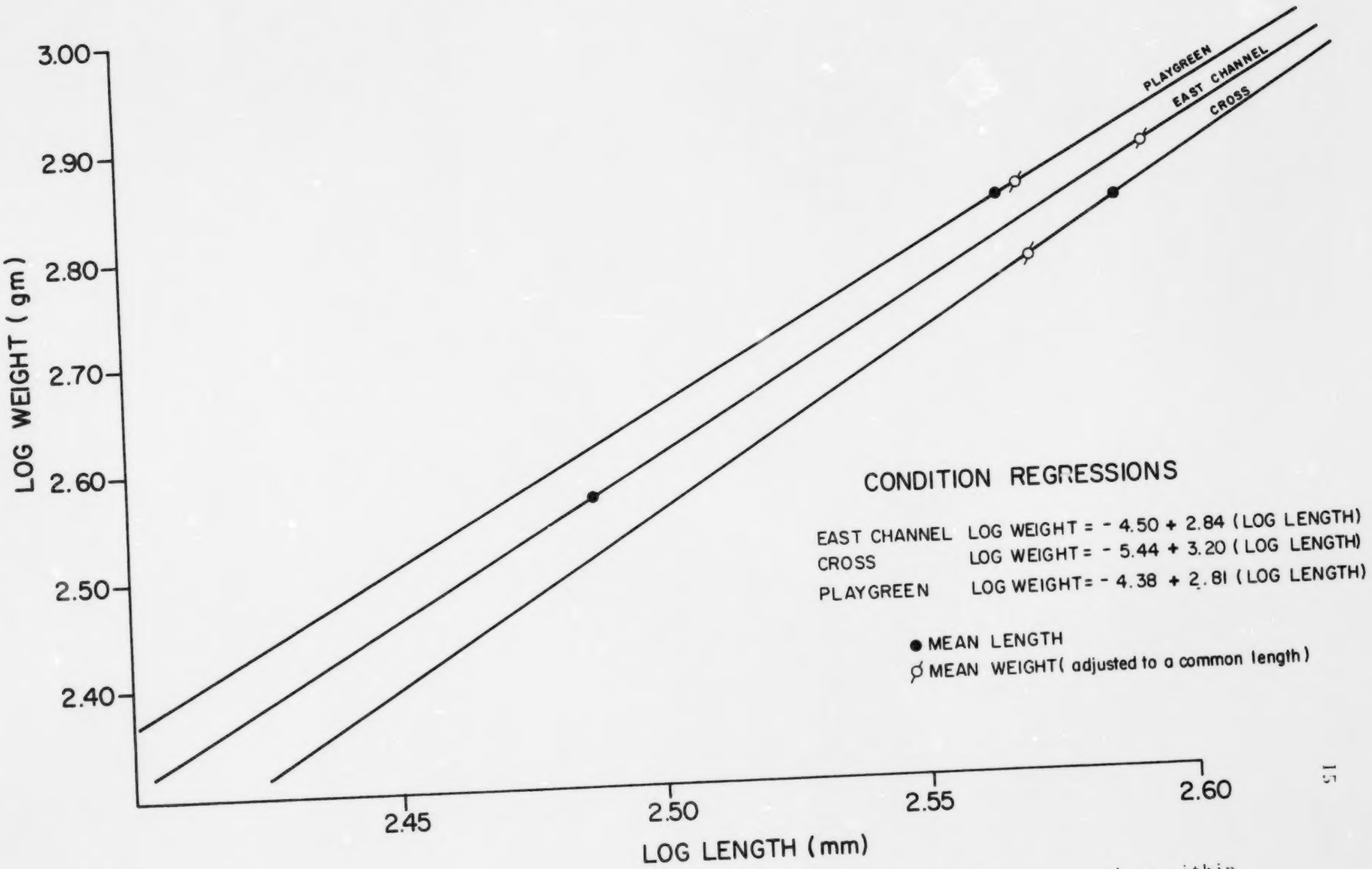
Catch per unit effort of 6 species of fish from different locations on the East Channel of the Nelson River, June, 1973.

Table 2 . Catch per unit effort in numbers from three areas on the upper Nelson River. All values have been adjusted mathematically to allow for differences in lengths of gill net.

	East Channel	Playgreen Ayles (1973)	Cross Koshinsky (1973)
Whitefish	-	51.3	17.4
Walleye	18.5	19.0	45.6
Sauger	-	1.2	0.4
Cisco	2.4	19.8	56.6
Burbot	0.5	0.8	1.2
Pike	5.8	23.0	23.4
Perch	0.5	6.0	.6
White sucker	8.3	8.4	10.2
Longnose sucker	1.0	0.7	-
Redhorse sucker	20.0	-	-
Total No.	57.0	130.2	155.4

Table 3. . Comparative length-at-age of walleye from three different locations on the Nelson River System. Values are fork length (inches) at age years.

	Age						
	2+	3+	4+	5+	6+	8+	9+
East Channel	8.8	10.7	14.1	14.2	15.9	16.5	17.8
Playgreen	12.3	13.1	14.5	16.0	18.1	20.2	21.0
Cross	7.9	11.1	14.3	15.5	17.0	16.6	-



three different locations within

Figure 3. Comparative condition regressions of walleye from the the Lake Winnipeg Outlet Lakes area.

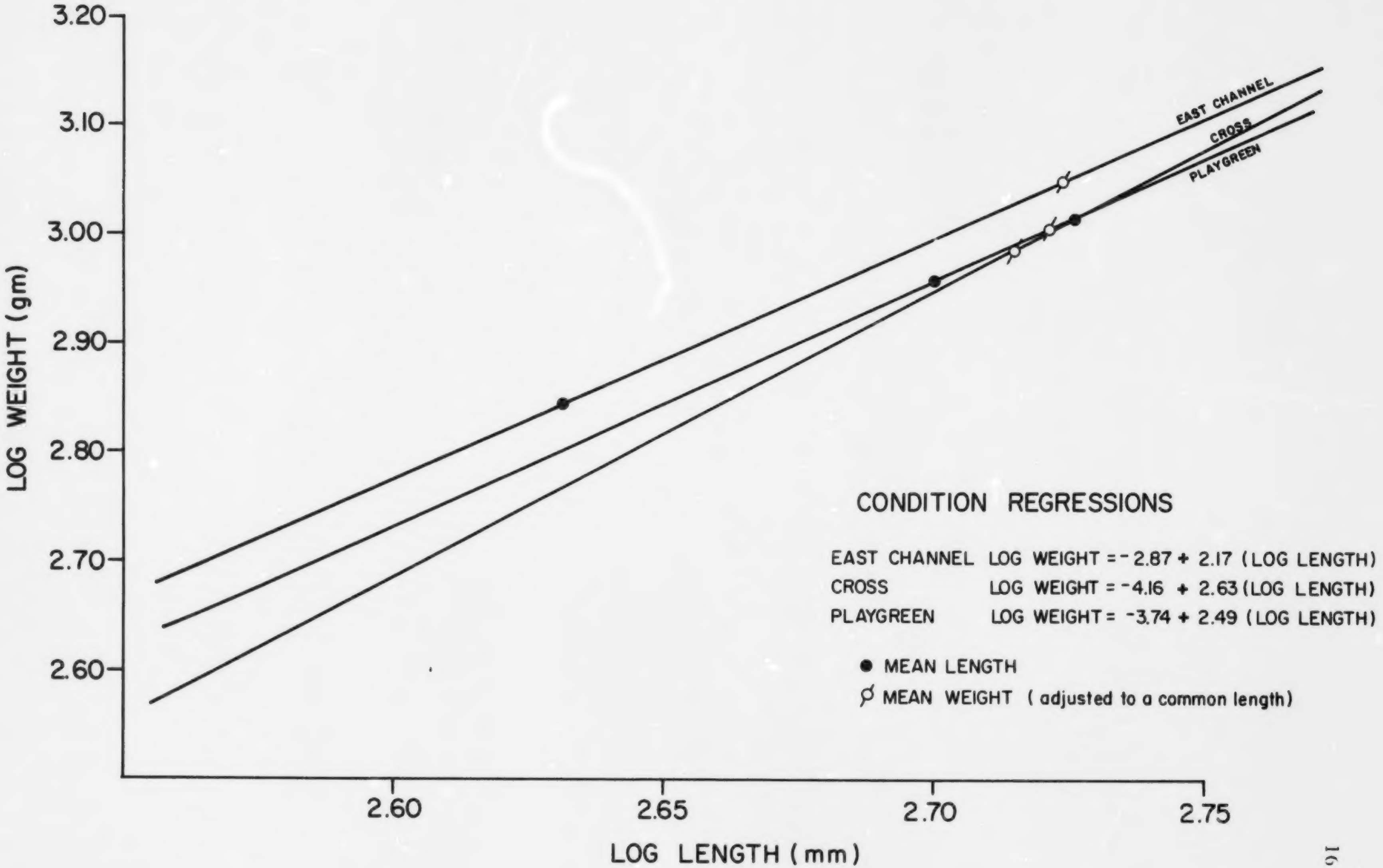


Figure 4. Comparative condition regressions of northern pike from three different locations within the Lake Winnipeg Outlet Lakes area.

Commercial and sport fishing

At the present, the East Channel is not commercially fished, no if present market conditions continue, is it likely to be fished in the future. Commercial fishing in northern Manitoba is primarily for white fish and with no whitefish and not an exceptional number of walleye the East Channel would not be economically reasonable for fishing.

As outlined by Koshinsky (1973) there is no existing sport-fishery in the Outlet Lakes area, there are no facilities established for such activities, and the local, and temporary (Hydro), residents in t area have little apparent interest in sport fishing. The East Channel is part of an existing canoe route and as such receives limited sport-fishing from visiting recreationists.

During the sampling period a record of the sports fish angled was kept, and an analysis shows that although pike were more plentiful than walleye (2.3 pike/hour, 0.3 walleye/hour) neither were in large supply, or near trophy size (the largest pike weighed approximately 1 pounds) However, with the construction of a dam at Sea River Falls, a tail-race environment should provide northern pike and possibly walley sport fishing opportunities.

Implications

A control structure at Sea River Falls could create two major problems with the fishery. Any obstruction, such as a control struc would prevent passage of fish along this channel. A reduction in wa levels and flows from historic mean levels during spring and early s could reduce survival rate for particular species of fish.

From the data, it would appear that there is no extensive mig of fish between Playgreen, the East Channel and Pipestone Lake. Howe it may exist at another time of the year, or in quantities just larg enough, between Playgreen and the East Channel, to maintain a simila in fish populations. The economic importance of any such movement i questionable. The East Channel is not commercially fished at presen and it is, as yet, sports fished infrequently. Whitefish from Playgr Lake could move as far as the Channel during spawning, but whitefish typically lake spawners and hence the Channel should be of little importance.

The control structure would be constructed to augment the flow in the West Channel by reducing the water flow in the East Channel. reduction of water flow to as low as 1,000 cfs (Water Resources, 1973 particularly during the periods of fish spawning and incubation (e.g. walleye and northern pike in late May and early June), would reduce wa levels in most channels, leaving fish spawning sites and incubating e dry.

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The reduction in flows through the East Channel would
increased residence time for the Nelson River water , decr
turbidity,and hence increased capacity for utilization of ava
nutrients. However, a reduction in water levels would also re
reduction in surface area of the East Channel and therefore a
in productive capacity within the Channel. Overall, there wou
little change in production in the East Channel.

Pipestone Lake, at the mouth of the East Channel, fluc
according to levels in Cross Lake, and should not show major c
water levels if the East Channel is regulated. Although a rec
Nelson River flows would increase the time it takes for a comp
exchange of lake water (from six days to thirty-six days, appr
this could actually allow for more complete utilization of ava
nutrients. Provided the flow from the East Channel would not
low, i.e. less than the historic mean low, production in Pipes
should not be unduly affected.

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RECOMMENDATIONS

1. There is little direct evidence for fish passage along the
Channel in the vicinity of Sea River Falls, however, invest
were completed at one particular time of year, and such evi
should not be extrapolated to describe all seasons of the y
Although Section 20(1) and Section 20(2) of the Canada, Fis
Act call for a fish passage facility at all obstructions on
Canadian water ways there has not been enough evidence, yet,
the recommendation to be made that a fish passage facility
be a part of any control structure at Sea River Falls. Ins
it is recommended that a fish attraction device be incorpor
into the control structure that could be converted to a pas
facility if the need were proven.

2. Although the fishery resource in the East Channel does not
to be of a large size, it could, in the future, have some
for limited recreational fishing. A reduction in flows, pa
during May, June, and early July would mean that areas of
East Channel would be dry. By the nature of the locations
for spawning by such fish species as walleye and pike it is
likely that the areas that would be dry are spawning sites
and other fish species. Therefore, it is recommended that
be great enough, at all times, to ensure that existing chann
contain water; and b) during May, June and early July flows
maintained at a level as high as 10,000 cfs, with no fluctua
allow for successful spawning and incubation of many fish sp

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present.

3. Reduction in East Channel flows to less than histor
(1,500 cfs) could reduce productivity in Pipestone
a level of nutrient availability, at least of the s
as the minimum provided historically, flows in the
and hence to Pipestone Lake during late winter and
period, should be maintained at least at the histor
levels.

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APPENDIX 5 - VOL. 2 - C

SUMMARY OF FISHERIES-LIMNOLOGY INVESTIGAT
ON THE LOWER CHURCHILL LAKES AND
ON THE RAT-BURNTWOOD LAKES

SUMMARY OF
FISHERIES-LIMNOLOGY INVESTIGATIONS ON THE LOWER CHURCHILL LAKES AND ON THE RAT-BURNTWOOD LAKES

by

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Winnipeg, Manitoba
August, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

INTRODUCTION

Hydroelectric development in northern Manitoba includes regulation of Lake Winnipeg and the upper Nelson River, raising Southern Indian Lake, and diversion of the Churchill River to the Nelson River through the Rat-Burntwood River systems. Each phase of the development will create changes to the existing aquatic ecosystems. The fisheries-limnology component of the Lake Winnipeg, Churchill and Nelson Rivers Study Board has attempted to describe the existing situation in all affected aquatic ecosystems excepting Lake Winnipeg, to predict how the hydroelectric development will affect these ecosystems, and to recommend appropriate mitigation measures.

Lake Winnipeg is excluded because the ecological implications appear to be minimal. The lake is only going to be raised less than one foot above the mean level, and its range of fluctuation will be maintained within the established high and low levels. These changes are not likely to affect the general productivity of the lake and it is unlikely that future changes in chemical or biological characteristics of the lake can be attributed to Lake Winnipeg regulation. Phytoplankton, zooplankton, zoobenthos, and fish populations and production will likely be unaffected and the availability of commercial species to standard commercial gear is likely to remain unchanged.

Field investigations on the three Churchill River lakes immediately downstream from Southern Indian Lake (Partridge Breast, Northern Indian, and Fidler), an adjacent Shield lake (Wood Lake), and 11 lakes on the

Rat-Burntwood River systems (Issett, Karsakuwigamak, Pemichigamau, Rat, East Mynarski, Central Mynarski, West Mynarski, Notigi, Wapisu, Threepoint, and Wuskwatim) were initiated during the winter of 1972, and continued through the open-water season of 1973. This report summarizes the results of the many studies conducted on these water systems and emphasizes major conclusions of the individual reports which are to appear as appendices to this summary.

LOWER CHURCHILL LAKES

Present conditions, Lower Churchill lakes:

The Churchill River within 50 miles downstream of Missi Rapids broadens into three sizable lakes, Partridge Breast, Northern Indian, and Fidler, before following a well defined river channel into Hudson' Bay. The three lakes have a combined surface area of 80 square miles with mean depths ranging from 9.8 feet to 20.7 feet (Fig. 1). The discharge from Southern Indian Lake into Partridge Breast Lake is approximately 35,500 cfs while discharge from Fidler Lake is estimated at 37,223 cfs. Local drainage is a very small component of the hydrological budget of these lakes, and the high discharge imposes a short exchange time on the water in the lakes, 1.3 days for Fidler to 9.0 days for Northern Indian. The climatic and geological setting of the lakes is nearly identical to that of Southern Indian Lake.

The limnology of these lakes is broadly similar to that of Southern Indian Lake which is expected from the overwhelming role the Churchill River plays in their hydrology. The chemical composition of the lakes is nearly identical with that of Southern Indian Lake discha As Southern Indian Lake presently retains only 10% of the phosphorus supplied to it, the lower Churchill lakes have very high nutrient loading rates, but the short exchange times dictated by the high discharge is not sufficient for effective utilization of the nutrients. In fact seasonal water quality changes in chemical composition and phytoplankton largely reflect upstream events in Southern Indian Lake as a result of the short exchange time. Also consequential to the rapid turnover and stronger currents present through the lower Churchill lakes the transparency of the water declines below Missi Rapids, and this decline in transparency accounts for somewhat lower algal productivity in these lakes as opposed to Southern Indian Lake. Contrary to limnological observations in Southern Indian Lake in 1972, there was evidence of oxygen depletion in lower Churchill lakes during the winter of 1973 with oxygen tensions after ice-out ranging from 31-77% of saturation. The winter depletion is partially due to thermal stratification under the ice retarding mixing. During the summer the lakes are isothermal and saturated with oxygen.

Phytoplankton standing crops and productivity in the mainstem portions of the lower Churchill lakes were comparable to, but generally lower, than in Southern Indian Lake near Missi Rapids. Average summer biomasses declined from Missi Rapids through Fidler Lake, and this could be correlated with increasing turbidity downstream attributable to stronger currents. Even in Fidler Lake algal standing crops generally exceeded those of Wood Lake, a nearby Shield lake off the Churchill. The distinction between Churchill-influenced stations and local drainage was especially apparent in late September, 1973 when mainstem stations exhibited 2-3 times the algal biomass and productivity of stations off the Churchill River plume. Diatoms predominated at all Churchill River stations while other algal groups were most abundant in bays and Wood Lake. The clear differentiation of algal populations at that time indicates restricted horizontal mixing of Churchill River water with bays and backwaters off the mainstem. Therefore, water exchange times calculated on the basis of lake morphometry and discharge rates wi

estimate the rapidity with which the Churchill plume traverses the

A similar phenomenon was earlier noted in Southern Indian Lake.

The numbers of planktonic crustaceans decrease rapidly in t Churchill River as compared with the abundances in Southern Indian Wood Lake and lakes on the Rat-Burntwood system. Also the number decreases; however, the dominant species are the same, indicating Southern Indian Lake is the main origin of the Lower Churchill Lak ton. This is rather typical for a riverine situation where the hi flushing rate does not even in very rich rivers create favourable ditions for crustacean plankton development. The local plankton n are well compensated by high benthic fauna abundance.

Standing crops of benthic organisms are comparable with tho Southern Indian Lake with the average number of organisms per unit being somewhat higher than in Southern Indian Lake. The density o benthic organisms in a nearby Shield lake, Wood Lake, was only 9-4 as high as densities in the three lower Churchill lakes. The fres water amphipod, Pontoporeia affinis, an excellent whitefish food w major component of the standing crops in all these lakes.

Northern Indian Lake and Fidler Lake presently support acti summer fisheries and during recent years the allowable quota has b frequently exceeded without apparent detriment to the fish stocks. present quota on all three lakes is 135,000 pounds which would be at $23,000 by 1972 prices. The yield per acre, 0.58 to 1.6 pounds 20-50% of that on Southern Indian Lake, 2.5 pounds per acre, but t differential probably reflects a lower intensity of effort as catc unit effort in experimental gillnets was generally similar to or som what better than that in Southern Indian Lake. The catch per unit effort in the experimental nets for the prime commercial species lak whitefish (Coregonus clupeaformis) was 50% to 100% higher in lower Churchill lakes than in nearby Wood Lake. The commercial harvest is almost exclusively whitefish although the experimental nets returned nearly equal weights of northern pike, Esox lucius. Experimental ne were not set with the intention of selective fishing, however, as th commercial sets are. Walleye (Stizostedion vitreum) was not promine in experimental nettings although the walleye catch per unit effort Northern Indian Lake was comparable to the average in Southern India Lake. Growth rates for whitefish were somewhat lower than on Southe Indian Lake, but condition was equally good. The data generated by t study indicate that the lakes are presently underexploited and that t have a potential for significantly higher yields; only effort is pres limiting the commercial yield.

In summary the present lower Churchill lakes appear to be as productive per unit area as those portions of Southern Indian Lake receiving Churchill River flow. In both lake systems the positive affect of river flow on biological productivity including fish is eas demonstrable. These riverine lakes are significantly more productive than nearby Shield lakes receiving only local drainage.

Impact of the lower Churchill lakes:

Diversion of up to 30,000 cfs out of South Bay on Southern Indi Lake into the Rat-Burntwood-Nelson drainage will drastically alter th hydrology of the lower Churchill River and its lakes. The water level

in the lakes are extremely sensitive to discharge as the control se
tend to be narrow and deep. Levels are maintained not so much by a
physical horizontal obstruction, e.g. a rock ledge, as by the resis
to flow offered by channel constrictions. If no weirs are construc
to compensate for decreasing the long-term average discharge at Mis
Rapids to 8,800 cfs from 35,500 cfs, the average elevation of these
will be decreased by 8.4-10.3 ft. Areal changes associated with th
lower levels range from a reduction of 39% in Northern Indian Lake
76% for Fidler under average conditions (Fig. 1). Under minimum d
allowable by the interim license (500 cfs in summer; 1,500 cfs in
the areas would be reduced another 20-30% of the post-diversion av

The operation of the diversion will also accentuate the peri
of discharge at Missi Rapids. Presently, average summer maximum m
discharges (July) are less than 50% greater than the average winte
monthly minimum (March). After diversion the average summer disch
in July will be 12 times the March discharge. Consequently the an
fluctuation in water levels of the lakes will increase from a rang
3.2-4.3 ft up to 7.2-8.7 ft. Initially after the diversion goes i
effect broad areas of littoral regions will be exposed. Much of t
will eventually be colonized by terrestrial communities, but a bro
band around the reduced lakes will be maintained in a state of dis
equilibrium by the large fluctuation in water levels. The lower w
levels after diversion will lead to erosion by wave action of sedi
deposited previous to diversion, and the eroded material will incr
turbidity over large areas of the lake. The greater annual drawdo
will likely create turbidity higher than the present level even af

most of the exposed mud flats are removed.

Lower discharges will increase exchange times somewhat in th lakes, but the large reductions in volume will largely offset the discharges. After diversion under average flow conditions, exchan times for the different lakes will range from 1.3 to 16.4 days as pared to 1.3 to 9.0 days presently. The lakes will still be river in nature and the major chemical constituents will reflect dischar at Missi Rapids.

Reduced flows could change mixing patterns in the lakes. A deep trough in Northern Indian Lake will be more likely to thermal stratify in summer than previously, but this trough is less than l of the total post-diversion lake area and consequently most of the in these lakes will remain isothermal and oxygen saturated through summer. In winter, however, the present pattern of thermal strati will intensify under the greatly reduced discharges. Presently th oxygen depletion that occurs during the winter months results in o concentrations after iceout that are only 31-77% of saturation. Af diversion these winter oxygen values may decline further.

The Fisheries-Limnology study has previously predicted that t will be appreciable changes in the hydrography of Southern Indian L north of Long Point. Increases in total dissolved solids, dissolve inorganic carbon, calcium and magnesium are expected and the lower Churchill lakes will reflect these changes. It is also expected th nutrient retention above Missi Rapids will increase as most of the Churchill flow is diverted out of South Bay and the greatly increas exchange time for the northern portion of Southern Indian Lake allo more efficient utilization of nutrients. Therefore, concentrations

phosphorus, in particular, will decline in the lower Churc
Annual loading rates per unit area will also decline, but
exchange times for these lakes under average post-diversio
makes the meaning of this reduced loading unclear. Presen
composition and standing crops of phytoplankton in the mai
the seasonality of the phytoplankton in Southern Indian La
general decline in standing crops from Missi Rapids to Fid
the increased turbidity and turbulence. In other words, m
algal crop is imported. The short exchange times even aft
will still maintain this pattern. A general decline to tw
present level has been predicted for algal production in S
Indian Lake and this decline will probably be evident in t
Churchill lakes.

It was mentioned before that the flushing rate after
remains unchanged as the large reduction in lake volumes w
offset the lower discharges. No substantial changes could
in the present, very low zooplanktonic abundance, as expres
of volume. However, due to essential lake volume reduction
abundance of plankton per lake will decrease proportionally
volume decrease.

For a per-unit-area basis the standing crops of zoobe
downstream Churchill lakes can be expected to stabilize at
two thirds present levels. The increased water drawdown an
lake size will, however, substantially reduce the area avai
colonization by zoobenthos.

Fish populations will eventually respond to the genera in the productivity of the lower trophic levels. With the probable qualitative and quantitative changes in benthos a reduction in the whitefish population will almost certainly occur. The decrease in food supply will be aggravated by a lower spawning success. New spawning sites will have to be established but rock areas will be unsuitable until wind and wave action resuspends and removes the existing sediment layers. Under average conditions falling water levels will be occurring during and just after whitefish spawning. Under natural conditions there is less than 5% chance of a two to four foot drop in September and October on Northern Indian Lake. After diversion, the corresponding probabilities are 58% in September and 20% in October and there is a 13% chance that water levels will drop by 4-6 feet. Water level changes on Fidler and Partridge Breast during this time will be even more severely affected. The magnitude and timing of these declines present hazards for deposited spawn. Walleye spawning during the spring in streams should be less severely affected, but deposited spawn may be flooded to greater depths than in natural conditions. The larger areas of unstable shorelines and mudflats after diversion will likely have a negative affect on pike spawning success as well.

The commercial fishery potential will be affected by reduced fish populations. Changes in the whole fish populations are likely to have the greatest impact. Catch per unit effort will decline and fishing effort on the lakes could cease entirely because of this. Lower lake levels would also entail the construction of new fish camp facilities to allow reasonable access to the new shoreline. Without new facilities the effort problem would be aggravated, but construction of such facilities would not guarantee the maintenance of the fishery when success is declining.

The foregoing assessment of probable impact forecasts lower biological productivity in the lower Churchill lakes which will exist after diversion under average conditions. Under minimum flow conditions allowable by the interim license the impact will be more severe with a general aggravation of the phenomena discussed above. With the accompanying complete loss of aquatic habitat due to lower water levels and reduced area, it is clear that there will be a drastic reduction in the potential fish production of the lower Churchill lakes. In addition to the lakes, the fish production of the lower Churchill River is threatened. The recently completed ice study by LaSalle Hydraulic Laboratories indicates that under minimum allowable discharges (present interim license) the lower Churchill River downstream of the lakes will freeze solid obliterating most aquatic life. The greater water level fluctuations on the lakes and the probability of freeze-out in the lower river stretches entail the risk of probable violations of the Federal Fisheries Act (which has been communicated to the Study Board through previous correspondence, see attached copies).

The construction of weirs at the outlets of these downstream Churchill lakes would stabilize water levels near present levels and would go a long way towards maintaining, or in some cases even improving production in these lakes. The reduced flushing rate would enhance the production of phytoplankton and zooplankton while zoobenthos and fish production would likely be maintained at or near present levels.

Recommendations for mitigation - lower Churchill lakes:

The Fisheries-Limnology component recommends the following mitigation measures which would in large measure prevent drastic decreases in potential fish production and general environmental degradation.

I. Weirs should be constructed at the outlets of the lakes to stabilize water levels near their present level and close to their present annual level of fluctuation. The weirs would maintain the surface area of the lakes at or near their present state and prevent loss of habitat. Weirs would ensure continued spawning success for whitefish, and maintain the potential fish production of the lakes near its present level. Stable water levels will ensure that present fish station facilities on the lakes could continue to be used, and the fishery will continue to enjoy a reasonable level of success and even expand. Weirs are also likely to have beneficial effects on wildlife (W. Cowan, C.W.S., personal communication).

II. The operating license should be rewritten to change the minimum allowable discharges. As presently written, during years of low rainfall and/or extreme power demands when discharge at Missi Rapids is reduced to maintain diversion flow, the lower Churchill River stretches will freeze out in winter, and lower productivity will occur in the lakes. If weirs are not constructed, more habitat loss would also occur because of lower water levels. Fisheries-limnology has previously recommended a minimum annual average discharge of 5,000 cfs at Missi Rapids to safeguard a reasonable level of productivity for the large northern basin of Southern Indian Lake. This discharge would be nearly 4,000 cfs below the expected average annual discharge. An annual discharge of 5,000 cfs is also considered adequate to maintain a good level of production in the lakes below Missi Rapids. In addition to a guaranteed annual discharge the allowable minimums for winter discharge at Missi must be increased. The LaSalle Laboratory suggests that 4,000 cfs be maintained at least through December 15 to allow the formation of a stable ice cover. They then suggest that flow could be reduced, but their report offers no figure for a minimum flow which would maintain flow after this date. As it is likely that stresses will occur on fish populations before complete freezeout and as the Fisheries Act relies on the opinion of the Minister to safeguard fish populations, a renegotiation of minimum winter flows is required. The problem poses some difficult technical and biological problems with which there is little previous experience. It is suggested that a technical committee be appointed by the Study Board to decide on acceptable minimum flows in winter. The committee might include representatives of Manitoba Hydro, the Province of Manitoba (Department of Mines, Resources and Environmental Management), Federal Government (Department of Environment, Fisheries and Marine Service, Operations Branch), and an engineering consultant. Until such a committee is formed, Fisheries-Limnology suggests a minimum winter discharge of 5,000 cfs as one which would with certainty maintain flow in the lower Churchill and permit biological populations to maintain reasonable levels of success.

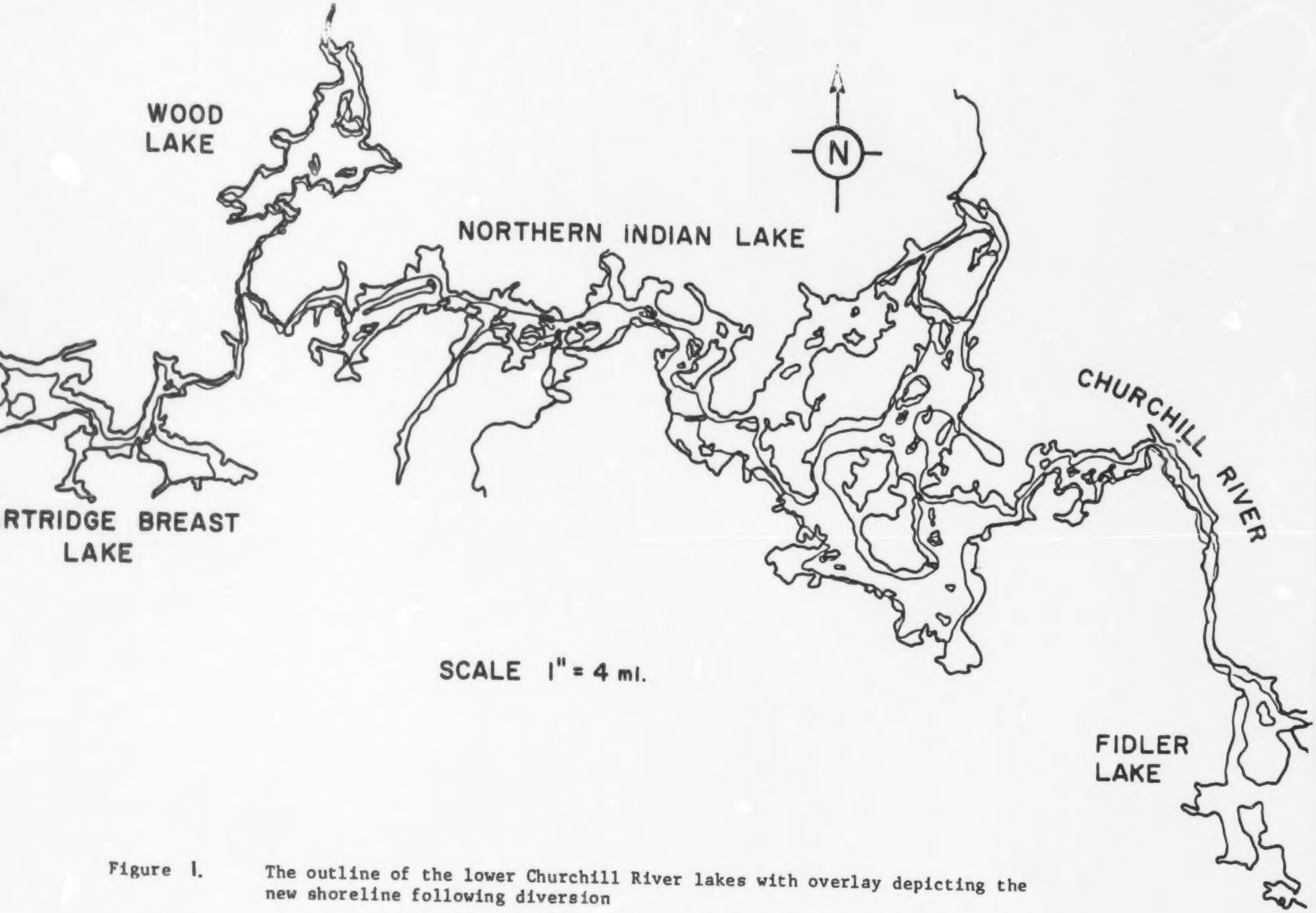

WOOD LAKE
N
NORTHERN INDIAN LAKE
CHURCHILL RIVER
RTRIDGE BREAST LAKE
SCALE 1" = 4 mi.
FIDLER LAKE

Figure 1. The outline of the lower Churchill River lakes with overlay depicting the new shoreline following diversion

RAT-BURNTWOOD LAKES

Present conditions - Rat-Burntwood lakes:

The diversion of the Churchill River from Southern Indian Lake to the Nelson River will involve the creation of one large lake along the existing Rat and lower Burntwood River system. A control structure just south of the existing Notigi Lake will raise the water level upstream from Notigi Lake to 850 feet; an increase of up to 56 feet. The addition of the Churchill River flow to the existing Rat River will decrease the time for exchange but will increase the nutrient loading of the river system.

The route of the Churchill River from Southern Indian Lake to the Nelson River will be through a relatively small river system; the Rat and Burntwood Rivers. The headwater lake of the Rat River is Issett Lake, approximately 5 miles southwest of South Bay, Southern Indian Lake. The Rat River drainage area (98°30' - 99°45'W by 55°30' - 56°40'N) comprises 2,700 square miles and contains both the Suwanee and Reading River drainage basins. It has a mean annual discharge at Wapisu Lake of 1,250 cfs. The Rat River and Footprint River join the Burntwood River at Threepoint Lake. Mean annual discharge of the Rat-Burntwood system at Wuskwatim Lake is 3,150 cfs. The climate of this area is similar to that of Southern Indian Lake.

The general geography of the area consists of an undulating glacio-lacustrine plain in the north with moderately rolling bedrock upland and extensive clay pockets in the south. The entire area is underlain with Precambrian bedrock and is in the discontinuous permafrost zone.

The existing lakes are, in general, relatively small with simple basins and regular shorelines. They vary in size from the smallest, Issett Lake with a surface area of 1.4 square miles to the largest, Rat Lake with an area of 33 square miles and mean depth of 12 feet (Fig. 2). The small size of the lakes allow for a relatively rapid exchange time (less than two months for all but Rat Lake).

The three Mynarski lakes, headwater lakes of the Reading River, a tributary to Rat Lake, are of similar size and complexity as the Rat River lakes. Although their volumes of water are similar, the lower flow of the Reading River (70 cfs) results in an exchange time 25 times greater than that for the Rat River lakes.

There is no significant thermal stratification of these lakes in summer. The isothermal condition, particularly in the Rat River lakes, is likely a result of the strong mixing action from turbulent flow in the riverine sections of the system and wind action on the lakes. As was the case with Southern Indian Lake, isothermal conditions and high rates of exchange provided conditions of near or total oxygen saturation in the Rat River lakes during the summer months. During the winter, thermal stratification does occur and biological respiration reduces the oxygen content of deep waters. Immediately after ice-out oxygen concentrations well below saturation are observed.

Chemical content of diversion route lakes is not unlike that found in South Bay of Southern Indian Lake. The diversion route lakes are high in calcium and total carbon dioxide, features unusual to Shield lakes, but reflecting the weathering of large pro-glacial lake sediments overlying Precambrian Shield. Light transmission is relatively poor, which is the result of a heavy sediment load introduced by erosion of the thick clay deposits. The Rat River provides a good supply of nutrients to the lake's system. While quantity of nutrients supplied is not greater than could be expected, because of the shallow basins, and high rates of turnover in the lake basins, annual nutrient loading is more than adequate at present.

Despite a high silt load, algal production in the diversion route lakes is relatively high. Values recorded for algal biomass during August, exceed maximum values stated for Southern Indian Lake, as well as values found for the lakes and reservoirs on the lower Nelson River. The quantities of crustacean plankton in the lakes of the Rat and Burntwood River system are slightly higher than those of Southern Indian Lake and are comparable to the abundances found in Lake Winnipeg. The species composition is similar in most lakes under study with *Cyclops vernalis*, *Diaptomus oregonensis*, *Diaptomus ashlandi* and *Chydorus sphaericus* being the most abundant components. They are about two orders of magnitude higher than the quantities in the lakes of the lower Churchill River system. This can be explained by the much lower flushing rates in the diversion route lakes as compared with the lower Churchill River lakes.

Densities of benthic invertebrates are generally much lower than in Southern Indian Lake or the downstream Churchill River lakes although they are not unusually low for typical Shield lakes. One might have expected that the relatively high values for algal biomass would have resulted in correspondingly high densities of benthic invertebrates. This was not the case. *Pontoporeia affinis* were not present in the samples from the Mynarski lakes. In the remaining lakes, this group along with the Chironomidae were the dominant taxa, however, because of their relatively low densities, they are not the large source of whitefish food they were in Southern Indian Lake and the lower Churchill lakes.

Numbers of fish taken by experimental gangs of gillnets varied considerably from numbers taken experimentally from Southern Indian Lake. Whitefish (Coregonus clupeaformis), walleye (Stizostedion vitreum), and northern pike (Esox lucius) were the commercial fish species present, with walleye predominating in number more often than whitefish. The average catch of whitefish from the diversion route lakes was one-fourth the size of an average catch of whitefish from Southern Indian Lake. This is likely a reflection of the quantity of benthic organisms available as whitefish food. Walleye appear to be more plentiful in the diversion route lakes than in Southern Indian Lake; however, in general, their condition was not as good as walleye from Southern Indian. Quantities and quality (i.e. mean weight) for northern pike were similar in the two systems.

Although in-depth investigations into locations of spawning sites for the major commercial fish species were not conducted, general observations were made, where possible, and recorded. Spawning sites for whitefish are generally clean, rock or boulder areas in lake shallows. Within the diversion route lakes, as they exist prior to impoundment, habitat such as this does exist in varied locations throughout the system. Indications are that walleye within the diversion route are stream spawners. One major river entering the Rat River system, the Reading River, was identified to be highly utilized by spawning walleye. Likely there are a large number of other tributaries to the

Rat system used by mature walleye as well.

When those diversion route lakes with a commercial fish quota (Pemichigamau, Rat, Notigi, Wapisu, Wuskwatim, and the Mynarskis) are fished they have an excellent commercial yield (up to 7 pounds per acre However they have never been intensively fished and such a high yield is likely, in part, an indication of an unexploited fish population. The lakes are underfished, producing approximately 30% of the quota yearly. Under-utilization does not appear related to production in these lakes, but rather to lack of effort, small quotas on individual lakes, and excessive distances to handling facilities for the fish. All fishermen are from Nelson House, but must arrange for transport of their catch to Leaf Rapids where it is shipped with the Southern Indian Lake catch. There are, on the average, 38 fishermen commercially licensed to fish 5 of the diversion route lakes. The extent of the domestic fishery was not investigated. Residents of Nelson House do remove fish from neighbouring lakes for their own consumption, however, the quantity does not appear to be great enough to adversely affect the fishery.

Whitefish comprise 80% of the commercial catch, walleye 14% and northern pike 6%. These relative figures are similar to those calculated for the commercial sized mesh (5 1/4") of the experimental gillnet.

Impact of diversion on the Rat-Burntwood Lakes:

A large lake, with extensive areas of inundated land will be created having a major impact on the existing system (Fig. 2). As well, a new supply of water with different chemical properties will be introduced to the system compounding the changes.

Mean depth of the Rat-Notigi reservoir will be approximately 7.1 meters and summer thermal stratification will not be extensive or prolonged as river currents and wind action will tend to keep the reservoir isothermal. However, thermal stratification is likely under ice, and the large inundated areas with biological decomposition will likely create oxygen depletions which will be especially severe in bays off the mainstem reservoir. Winter oxygen conditions will eventually improv as organic soils are buried by sediments or are mineralized, but data from Kettle Reservoir indicate that low oxygen conditions can persist at least 10 years after impoundment.

The flooding of organic soils and erosion of the shoreline will release nutrients into the water. The nutrients, even if biologically available, are unlikely to increase primary production markedly as nutrient loading by the Churchill River will be quite high. More significant will be sediments added from eroding shorelines which will decrease the transparency of inflowing Churchill River water which has a greater Secchi disc depth than the present Rat River. Conditions in the upper reservoir in the vicinity of the diversion channel are likely to be especially severe as the shallow depths, strong currents, and wind action will not allow materials to settle. Below the Rat-Notigi Reservoir where active channel cutting will occur there will be at least a fourfold increase in total suspended solids over the natural condition and this will greatly reduce light penetration in Wapusi, Threepoint and Wuskwatim.

An increased sediment load will adversely affect algal production in the new reservoir. Until some measure of shoreline stabilization is reached and the reservoir begins to clear algal production on a per-u area basis will remain lower than its pre-impoundment levels. Below the reservoir algal production will decrease in proportion to the large increase in suspended sediments. As a result of increasing flushing rates the crustacean plankton will decrease in numbers - in particular in the lakes below Rat-Notigi Reservoir and one can expect a situation comparable with the present plankton abundance in lakes o the lower Churchill River.

The areas exposed during winter drawdown will be relatively unsuitable for colonization by benthic invertebrates; however in othe areas the additional nutrients and organic materials in the modified environment will support substantial populations of benthic invertebr In general the production of zoobenthos on a per-unit-area basis will increase and will likely eventually equilibrate at levels similar to those presently found in the lower Churchill River lakes.

Relative population sizes of different species of fish will cha considerably. Whitefish spawning habitat will be restricted to those areas appearing now as rock outcrops until shoreline stabilization occurs and clear rock areas are available at the optimum depths. Whitefish will not disappear entirely, but their numbers on a per-uni area basis will be reduced.

Streams suitable for spawning walleye will, in most cases, be completely inundated. Some streams will remain, but the reduction in availability of spawning habitat will reduce numbers of walleye at least temporarily. Below the reservoir, walleye may move to the tailrace area of the control structure, particularly during the time of spawning, providing a concentration of this species ideal for spor fishing.

The new reservoir will create large areas of excellent nor pike spawning habitats, i.e. areas of standing vegetation in lak shallows. As well, typical pike food (small fish) will still be able in sufficient quantity. Therefore, the new reservoir should an excellent source of northern pike, (as is the case in Sipiwesk and it is not unreasonable to assume that pike of trophy size wil produced.

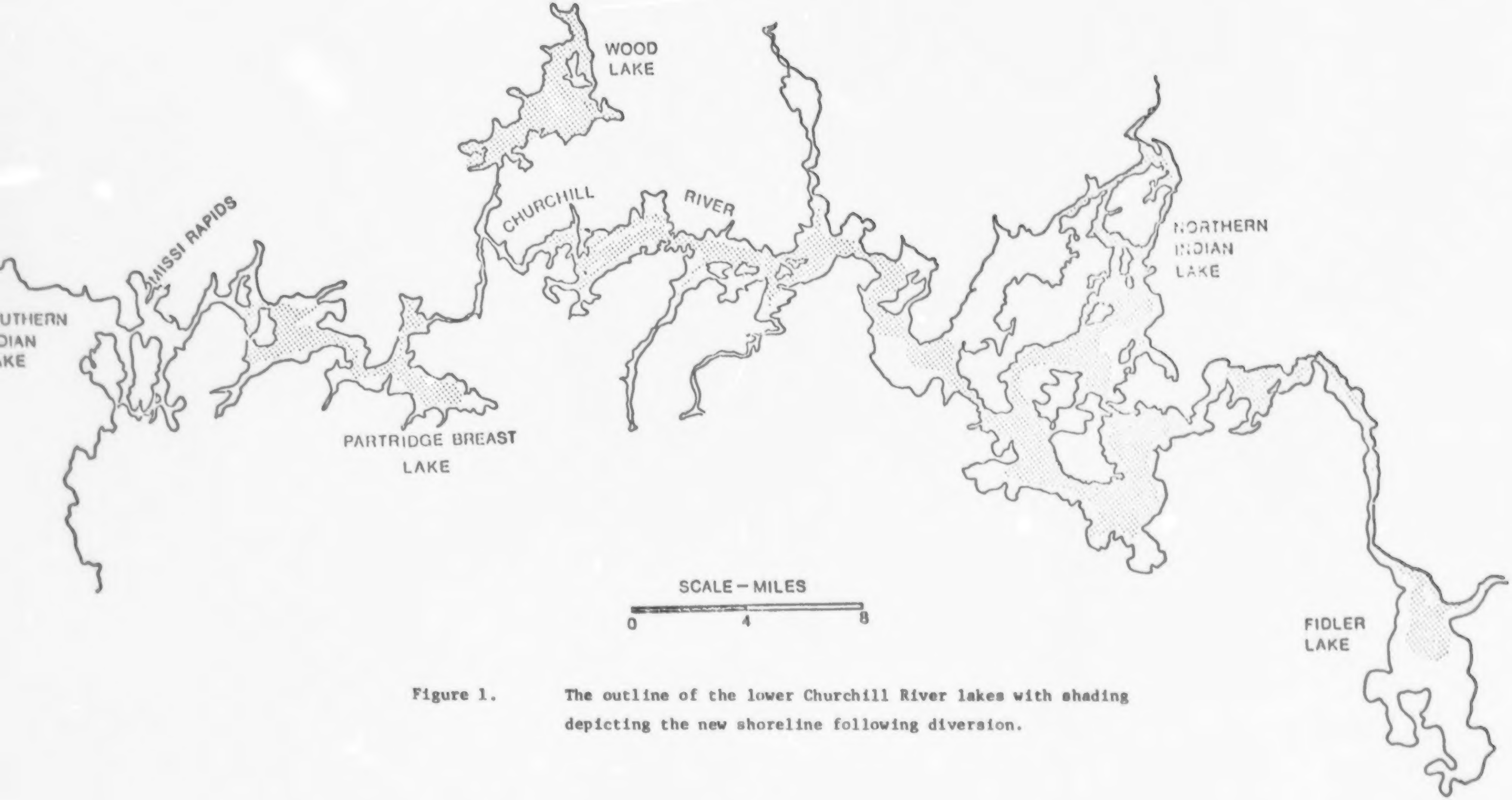
The impacts of the formation of a new reservoir to the comm fishery will be extensive. The large areas of flooded timber and release of floating and submerged debris will make the successful of gillnets close to impossible. In many areas of the lake, acce the shoreline will be hazardous and as well fish camps on Rat, No and Mynarski Lakes will be flooded. The result will be a likely reduction of the commercial fishery of from 90 to 100%.

Recommendations for mitigation - Rat-Burntwood Lakes:

Faced with such extensive changes to the environment it is difficult to recommend mitigation measures that would be meaningfu Clearing for whitefish spawning, as has been recommended for South Indian Lake, would be unreasonable in the Rat-Notigi Reservoir. N clearing for walleye spawning areas is being recommended because n enough is known about where the walleye will attempt to spawn foll inundation of their existing spawning beds. Since a commercial f is not likely to be viable at least until the new system has stabi a "wait-and-see" attitude with respect to relocation of fish camps recommended.

Many of the questions raised by this hydroelectric de have been impossible to answer adequately because the envir implications of developments of this size and at this latit simply not well enough understood. One of the most importa concerns the effects of various timber clearing practices o processes, shoreline stabilization rates, and ultimately th productivity of the inundated areas. As previously communi experimental clearing of selected areas in the Notigi Reser provide a real opportunity to produce some definitive answe critical questions concerning clearing practices. This kno also be very applicable to future reservoirs to be construc in northern Canada.

Potentially, the greatest benefit of the Lake Winnipe and Nelson Rivers Study is that there is now a wealth of ba information that can be compared with information gathered studies. Every effort should be made to ensure that resour available to adequately monitor major changes that do occur altered areas.


WOOD LAKE
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PARTRIDGE BREAST LAKE
NORTHERN INDIAN LAKE
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SCALE – MILES
0
4
8

Figure 1. The outline of the lower Churchill River lakes with shading depicting the new shoreline following diversion.

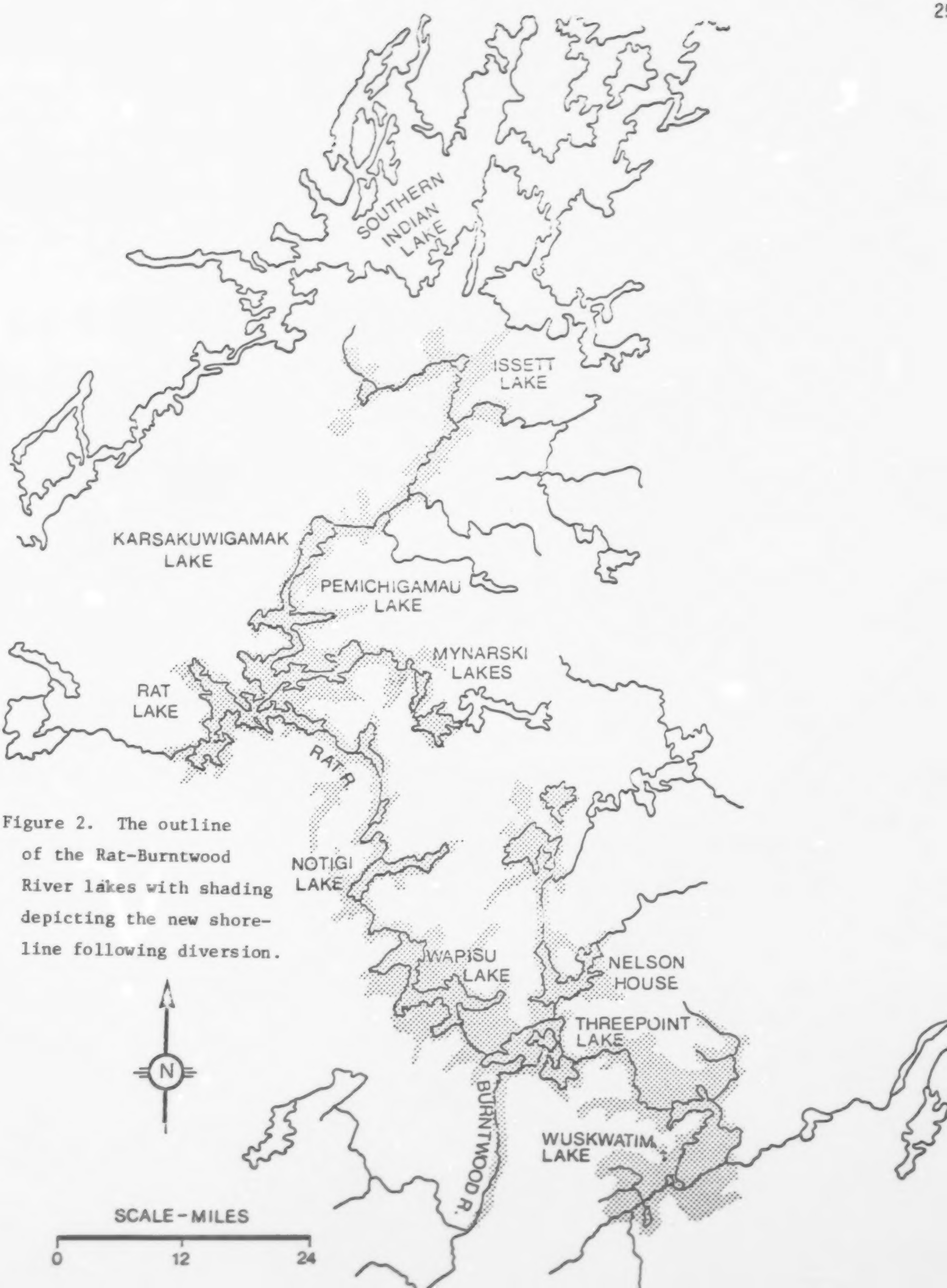
SOUTHERN INDIAN LAKE
ISSETT LAKE
KARSAKUWIGAMAK LAKE
PEMICHIGAMAU LAKE
MYNARSKI LAKES
RAT LAKE
RAT R.
NOTIGI LAKE
WAPISU LAKE
NELSON HOUSE
THREEPOINT LAKE
BURNTWOOD R.
WUSKWATIM LAKE
N
SCALE-MILES
0
12
24

Figure 2. The outline of the Rat-Burntwood River lakes with shading depicting the new shoreline following diversion.

APPENDIX 5 - VOL. 2 - D

THE MORPHOMETRY OF RAT-BURNTWOOD DIVERSION ROUT AND LOWER CHURCHILL RIVER LAKES: PRESENT CONDITIONS AND POST REGULATION CONDITIONS

THE MORPHOMETRY OF RAT-BURNTWOOD DIVERSION ROUTE AND LOWER CHURCHILL RIVER LAKES:

PRESENT CONDITIONS AND POST REGULATION CONDITIONS

by

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Winnipeg, Manitoba
July, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

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INTRODUCTION

Basin morphometry (e.g. lake size, volume, depth, etc.) is important for the description of various aquatic habitats and for estimating potential commercial fishery yields. Since Manitoba Hydro plans to regulate Southern Indian Lake and divert the flow of the Churchill River through the Rat-Burntwood River system to develop hydroelectricity it is useful to morphologically describe the systems affected. Cleugh et al. (1974) has discussed the morphometr of Southern Indian Lake. The following sections will discuss the morphometry of the Lower Churchill River lakes (Fig. 1, area B) most directly affected and the lakes on the Rat-Burntwood diversion route (Fig. 1, area A).

The methods and equipment used for sounding are similar to those employed by Cleugh et al. (1974). Bathymetric maps were prepared from sonar transects and the original lake outline prepared from aerial mosaics adjusted to two inches to the mile. The data was reviewed with references made to Hutchinson's (1957) methods. Morphometric parameters have been outlined in Tables 1-5 for the Rat-Burntwood diversion route lakes and in Tables 6-9 for the Lower Churchill River lakes.

RAT-BURNTWOOD DIVERSION ROUTE LAKES

Geography:

The Rat-Burntwood study area consists of eight major lakes situated in the main flow of the diversion: Issett, Karsakuwigama Pemichigamau, Rat, Notigi, Wapisu, Threepoint, and Wuskwatim. As Central Mynarski Lake, West Mynarski Lake, and Footprint Lake will be affected. These lakes form a major portion of the Rat-Burntwoo drainage system (Fig. 1A) and are situated at 98 30'-99 45'W by 55 56 40'N. Issett Lake is one of the main headwater lakes of the Rat River and will be the first lake influenced by the increased flow the Churchill River. The Rat River then flows through Karsakuwigam and Pemichigamau Lakes into Rat Lake. Here the Rat system is joine the Suwanee River drainage and the Reading River drainage which includes the Mynarski lakes. The Rat River then flows out of Rat L through Notigi Lake and Wapisu Lake to Threepoint Lake where it joi the Burntwood and Footprint Rivers. The Burntwood River then conti through Wuskwatim Lake, past Thompson, and discharges into the Nels River system at Split Lake.

The bedrock of the area is Precambrian consisting mainly of granitic rocks with some sedimentary rocks and their derived schist and gneisses. Near Karsakuwigamak Lake there is a small area of volcanic rocks (Davies 1962).

Underwood & McLellan (1970) divide the Rat-Burntwood diversion route into four physiographic areas:

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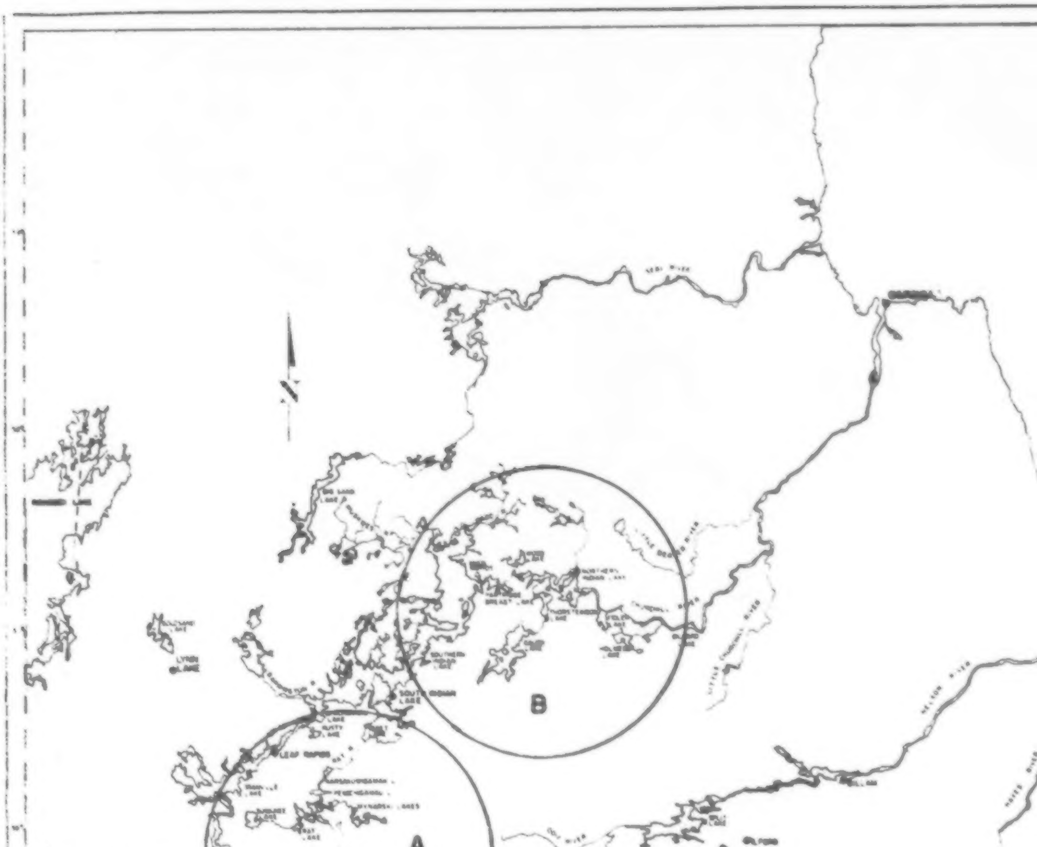
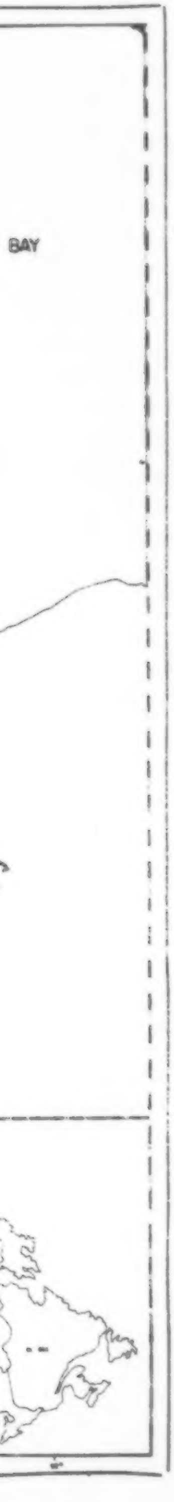

B
A
THOMPSON
Scale 1" = 90 mi

Figure 1. Map of northern Manitoba indicating study areas.



(1) Issett Lake - Pemichigamau Lake

(2) Pemichigamau Lake - Wapisu Lake

(3) Wapisu Lake - Threepoint Lake

(4) Wuskwatim Lake - Split Lake

The first region consists of undulating glacio-lacustrine plain deposited by glacial Lake Agassiz with few bedrock outcrop ridges. All regions of the Rat-Burntwood study area are in a zo discontinuous permafrost (Brown 1970). In the first region perm is found in the lower slopes and flatlands in both clay and orga deposits.

The second area from Pemichigamau to Wapisu consists of r bedrock uplands with extensive rock outcrops and till ridges. Pe frost occurs only in the organic deposits.

The third region, Wapisu and Threepoint Lakes, is moderate rolling bedrock uplands with extensive clay pockets. Permafrost found only in the organic deposits.

From Wuskwatim Lake to Split Lake the region is again roll clay plain with permafrost mainly in the organic deposits.

The bulk of the Rat-Burntwood River study area is placed i Nelson River and northern coniferous sections of the Boreal Fores Region (Whidden 1973). The tree species consist of black spruce, spruce, jack pine, balsam fir, tamarack, aspen, poplar, and birch. Sedges and mosses cover the marsh-muskeg areas.

The climate is cold continental with a mean annual temperat from 24°-26°F. Precipitation ranges from 14-16 inches yearly, one of which falls as snow (Weir 1960). Mean freezeup for lakes and b occurs around November 1 and later for rivers around November 10.

Breakup occurs near May 10 for rivers and around May 20 for la bays.

There is a permanent settlement in the Rat-Burntwood ar Nelson House (pop. 1,500) on Footprint Lake. The region is ac by provincial road 391 and various winter roads. Some of the however, can only be reached via water or aircraft.

Morphometry - present conditions:

The general morphometric parameters of the Rat-Burntwoo have been outlined in Tables 1-3. The lakes are listed in geo order beginning with Issett Lake located near Southern Indian finishing with Wuskwatim Lake located 78 miles to the southeas 3 lists cumulative drainage areas and approximate mean annual These outflows were estimated by calculating the percentage dr area of each lake compared to the total drainage area of the R Burntwood system to Thompson. Since flow recordings are made Thompson, by multiplying the fraction of contribution of each the total area by the mean annual flow for the Burntwood River Thompson an outflow value for each lake could be estimated. T method assumes a constant runoff for the total area and does n variables such as evaporation or the excess of inflow over out a lake. These values have a good correlation to those found b Manitoba Water Resources (1090 to 1165 for Notigi flows and 31 for Wuskwatim Rapids). Flushing times were calculated assumin mixing of water in all regions of a particular lake.

Issett Lake (Fig. 2) is the smallest of the lakes studie a water area of 1.4 square miles. It has only 4 small islands

Table 1. General morphometric parameters for eleven diversion route lakes.

	Issett Lake[1]	Karsakuwig-amak Lake	Pemichigamau Lake	Rat Lake	West Mynarski Lake	Central Mynarski Lake	East Mynarski Lake	Notigi Lake	Wapisu Lake	Threepoint Lake	Muskwatim Lake
Total area km^2	3.7	19.2	19.5	85.3	6.3	13.0	20.2	15.1	40.9	59.4	46.4
(mi^2)	(1.4)	(7.4)	(7.5)	(32.9)	(2.4)	(5.0)	(7.8)	(5.8)	(15.8)	(22.9)	(17.9)
Water area km^2	3.7	18.8	19.3	78.4	6.2	11.5	19.0	15.1	38.9	47.0	45.4
(mi^2)	(1.4)	(7.3)	(7.4)	(30.3)	(2.4)	(4.4)	(7.4)	(5.8)	(15.0)	(18.1)	(17.5)
Maximum depth m	-	11.5	5.0	14.5	8.5	15.0	19.5	12.5	10.0	7.0	12.0
(ft)		(37.5)	(16.4)	(47.6)	(27.9)	(49.2)	(64.0)	(41.0)	(32.8)	(23.0)	(39.4)
Mean depth m	-	2.0	2.2	3.7	1.7	2.7	4.2	5.3	3.3	0.7	6.2
(ft)		(6.6)	(7.2)	(12.2)	(5.5)	(8.9)	(13.6)	(17.4)	(10.9)	(2.3)	(20.4)
Mean depth ÷ Maximum depth	-	0.17	0.43	0.26	0.20	0.18	0.21	0.42	0.33	0.10	0.52
No. of islands	4	24	24	153	4	25	28	17	99	16	40
Island area km^2	0.01	0.5	0.2	6.9	0.1	1.5	1.2	0.1	2.0	12.4	1.0
(mi^2)	(0.01)	(0.2)	(0.1)	(2.6)	(0.1)	(0.6)	(0.4)	(0.1)	(0.8)	(4.8)	(0.4)
Insulosity %	0.2	2.3	1.2	8.2	1.0	11.4	5.8	0.2	4.8	0.3	2.0
Shore length total km	10.7	42.3	41.5	274.8	28.2	57.4	74.7	55.4	181.9	94.3	61.8
(mi)	(6.6)	(26.3)	(25.8)	(170.8)	(17.5)	(35.7)	(46.4)	(34.4)	(113.0)	(58.6)	(38.4)
Lake outline km	10.3	33.7	36.6	231.2	26.7	41.0	66.0	52.5	149.4	66.9	46.0
(mi)	(6.4)	(20.9)	(22.7)	(143.7)	(16.6)	(25.5)	(41.0)	(32.6)	(92.8)	(41.6)	(28.6)
Shore length islands km	0.4	8.6	4.9	43.6	1.5	16.4	8.7	2.9	32.5	27.4	15.8
(mi)	(0.2)	(5.4)	(3.1)	(27.1)	(0.9)	(10.2)	(5.4)	(1.8)	(20.2)	(17.0)	(9.8)
Shore development	1.50	2.19	2.36	7.37	3.03	3.41	4.27	3.81	6.75	2.75	1.92
Shore development incl. islands	1.56	2.76	2.67	8.76	3.19	4.78	4.83	4.02	8.23	3.88	2.58
Exchange time days	-	37	39	136	60	213	759	30	42	5	37
Altitude m	250.6	248.5	248.5	247.9	249.1	251.2	264.6	242.1	240.2	237.2	229.6
(ft)	(822)	(815)	(815)	(813)	(817)	(824)	(868)	(794)	(788)	(788)	(753)
No. of transects	-	39	48	104	35	24	11	12	24	19	3

[1] Issett Lake not sounded

Table 2. Areas of contours and volumes for ten diversion route lakes.

	Karsakuwig-amak Lake	Pemichig-amau Lake	Rat Lake	West Mynarski Lake	Central Mynarski Lake	East Mynarski Lake	Notigi Lake	Wapisu Lake	Threepoint Lake	Wuskwatim Lake
Area of 0 m contour km^2	18.8	19.3	78.4	6.2	11.5	19.0	15.1	38.9	47.1	45.5
(mi^2)	(7.3)	(7.5)	(30.3)	(2.4)	(4.4)	(7.4)	(5.8)	(15.0)	(18.2)	(17.6)
Area of 1 m contour km^2	-	-	-	3.3	-	-	-	-	-	-
(mi^2)				(1.2)						
Area of 2 m contour km^2	11.1	11.1	-	-	-	-	-	-	0.2	-
(mi^2)	(4.3)	(4.3)							(0.1)	
Area of 3 m contour km^2	1.8	5.3	-	1.1	-	-	-	-	-	-
(mi^2)	(0.7)	(2.0)		(0.4)						
Area of 5 m contour km^2	0.8	0.1	22.2	0.5	1.5	5.4	7.5	9.2	0.1	37.1
(mi^2)	(0.3)	(<0.1)	(8.6)	(0.2)	(0.6)	(2.1)	(2.9)	(3.6)	(<0.1)	(14.3)
Area of 10 m contour km^2	-	-	2.6	-	0.1	1.5	2.7	0.1	-	1.7
(mi^2)			(1.0)		(<0.1)	(0.6)	(1.1)	(<0.1)		(0.7)
Area of 15 m contour km^2	-	-	-	-	-	0.6	-	-	-	-
(mi^2)						(0.2)				
Volume m^3 x 10^6	37.77	41.90	291.25	10.42	31.46	79.03	79.98	128.83	33.92	283.95
(acre-feet x 10^4)	(3.06)	(3.39)	(23.61)	(0.84)	(2.55)	(6.07)	(6.48)	(10.44)	(2.75)	(23.02)

Table 3. Estimated mean annual outflows of eleven diversion route lakes.

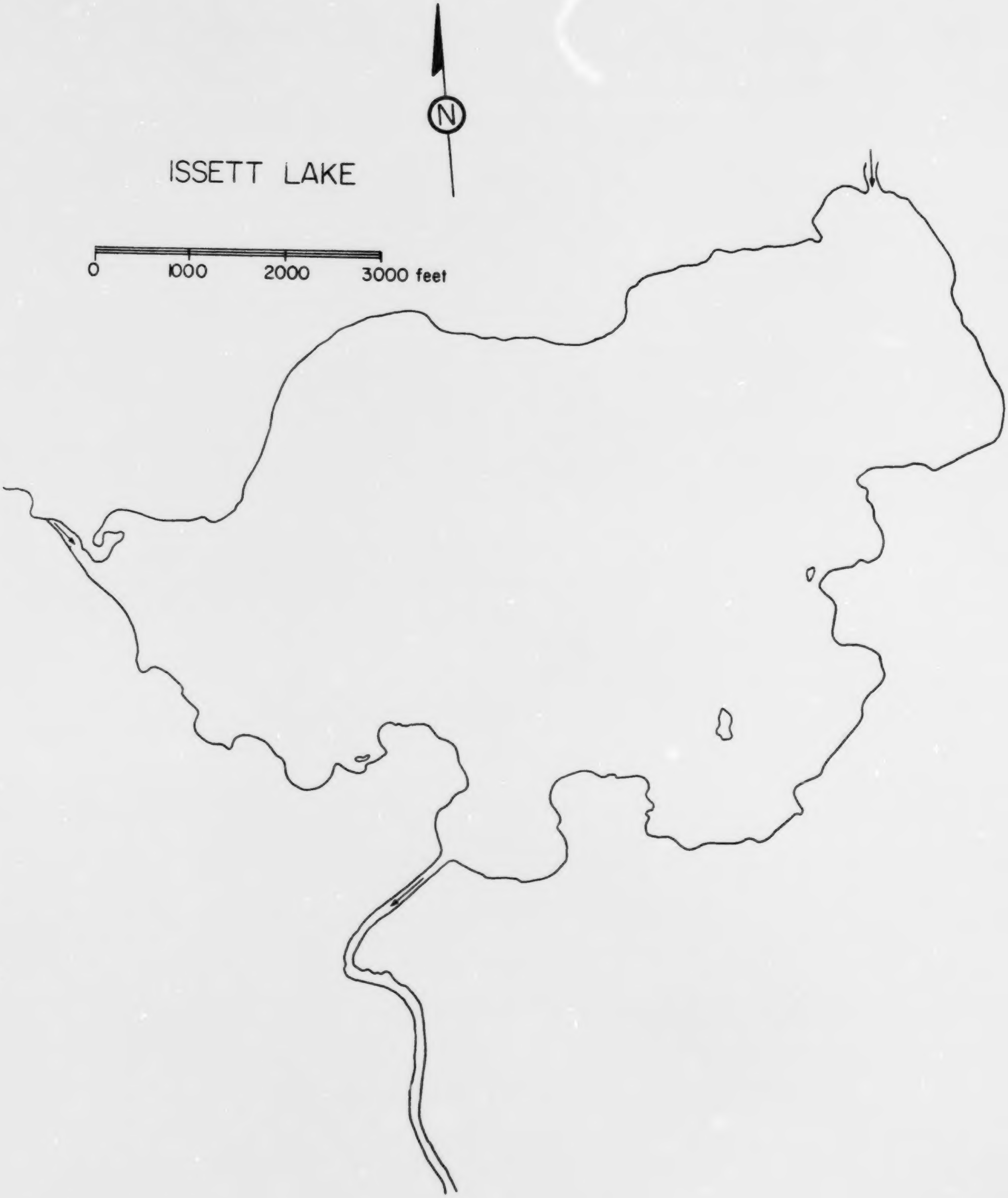
Location on Rat-Burntwood River system	Cumulative Drainage area sq. mi.	Percentage total area	Approximate outflow cfs.
Issett Lake	163	2.3	80
Karsakuwigamak Lake	813	11.6	410
Pemichigamau Lake	863	12.4	440
Rat Lake	1709	24.6	870
Notigi Lake	2133	30.6	1090
Wapisu Lake	2440	35.1	1250
Threepoint Lake	5772	82.9	2940
Wuskwatim Lake	6173	88.7	3150
East Mynarski Lake	75	1.1	40
Central Mynarski Lake	115	1.7	60
West Mynarski Lake	129	1.9	70

The modified historic mean annual flow of Burntwood River at Thompson is 3,549 cfs. (Manitoba Water Resources 1973).

Total drainage area of Rat-Burntwood system to Thompson is 6,960 square miles (Underwood, McLellan & Associates 1973, confirmed by D.S. Magnusson, Man. Hydro).

Drainage area of Burntwood River above Threepoint Lake 2,658 square miles (Fedoruk 1970).

Other drainage areas found by dot grid on National Topographical maps. Scale 1:250,000.



ISSETT LAKE
N
0
1000
2000
3000 feet

Figure 2. Outline map of Issett Lake.

in an insulosity of 0.2%. It has a relatively regular circular outline yielding a very low shore development (1.50 or 1.56 including islands). The drainage area of 163 square miles results in an approximate mean annual outflow of 80 cfs. The lake was not sounded.

Karsakuwigamak (Fig. 3), the next lake on the Rat river system, is somewhat larger with a water area of 7.3 square miles and a length of 5.8 miles. The elongate basin lies parallel to the river flow and has a $\bar{z}/Zm$[1] ratio of 0.17. This is quite low and is due to the presence of a deep channel in the center of the basin with the rest of the lake being relatively shallow. The shoreline is fairly regular giving a shore development of 2.19 or 2.76 including islands.

Pemichigamau Lake (Fig. 4) has approximately the same water area (7.4 sq. mi.) as Karsakuwigamak Lake but morphologically it is somewhat different. The long axis of the lake is situated perpendicular to the flow of the Rat River. Furthermore the lake is quite shallow having a Zm of 16.4 feet. The $\bar{z}/Zm$ ratio is quite high (0.43) indicating a tendency to a more uniform U-shaped bottom than Karsakuwigamak Lake. Shore development is similar to Karsakuwigamak at 2.36 or 2.67 including islands.

Rat Lake (Fig. 5) is the largest of the lakes studied in this region. It has a water area of 30.3 square miles. Rat Lake has an intricate shoreline attested to by the high shore development (7.37 or 8.76 including islands). The lake has an irregular shape consisting of three main basins. The east basin receives the inflow of the Rat and

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[1] $\bar{z}$ - mean depth
Zm - maximum depth

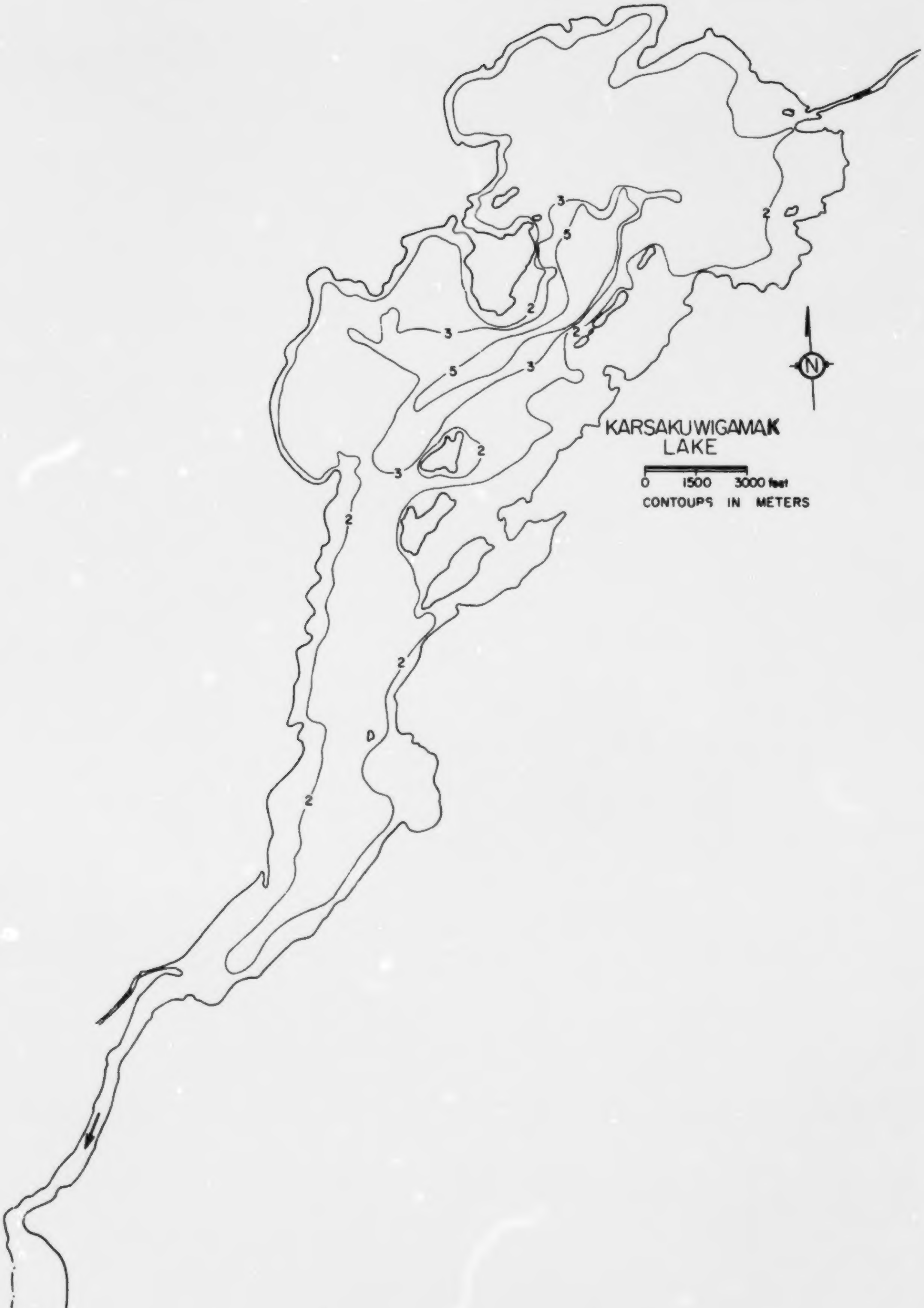
KARSAKUWIGAMAK LAKE
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Figure 3. Bathymetric map of Karsakuwigamak Lake.

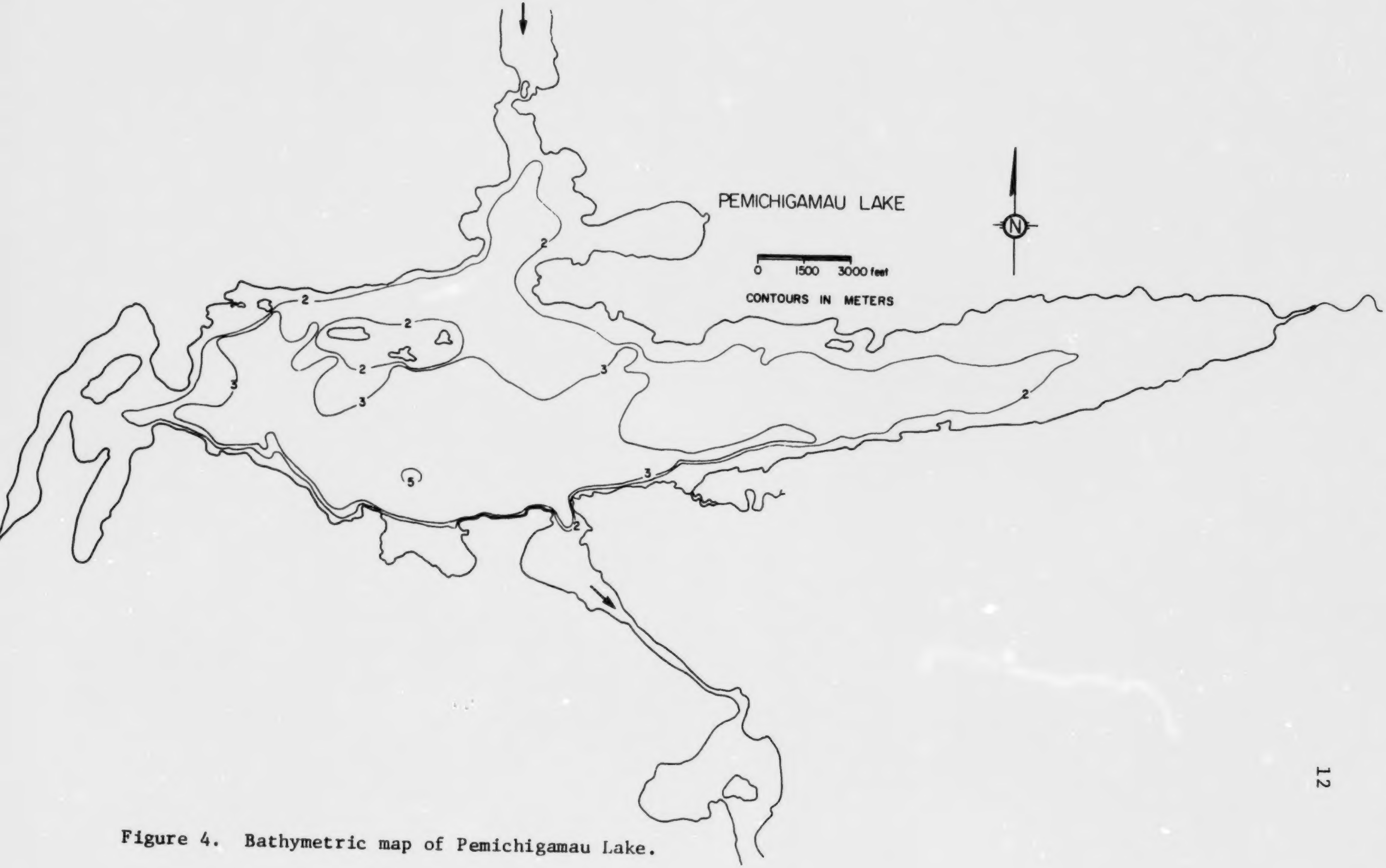
PEMICHIGAMAU LAKE
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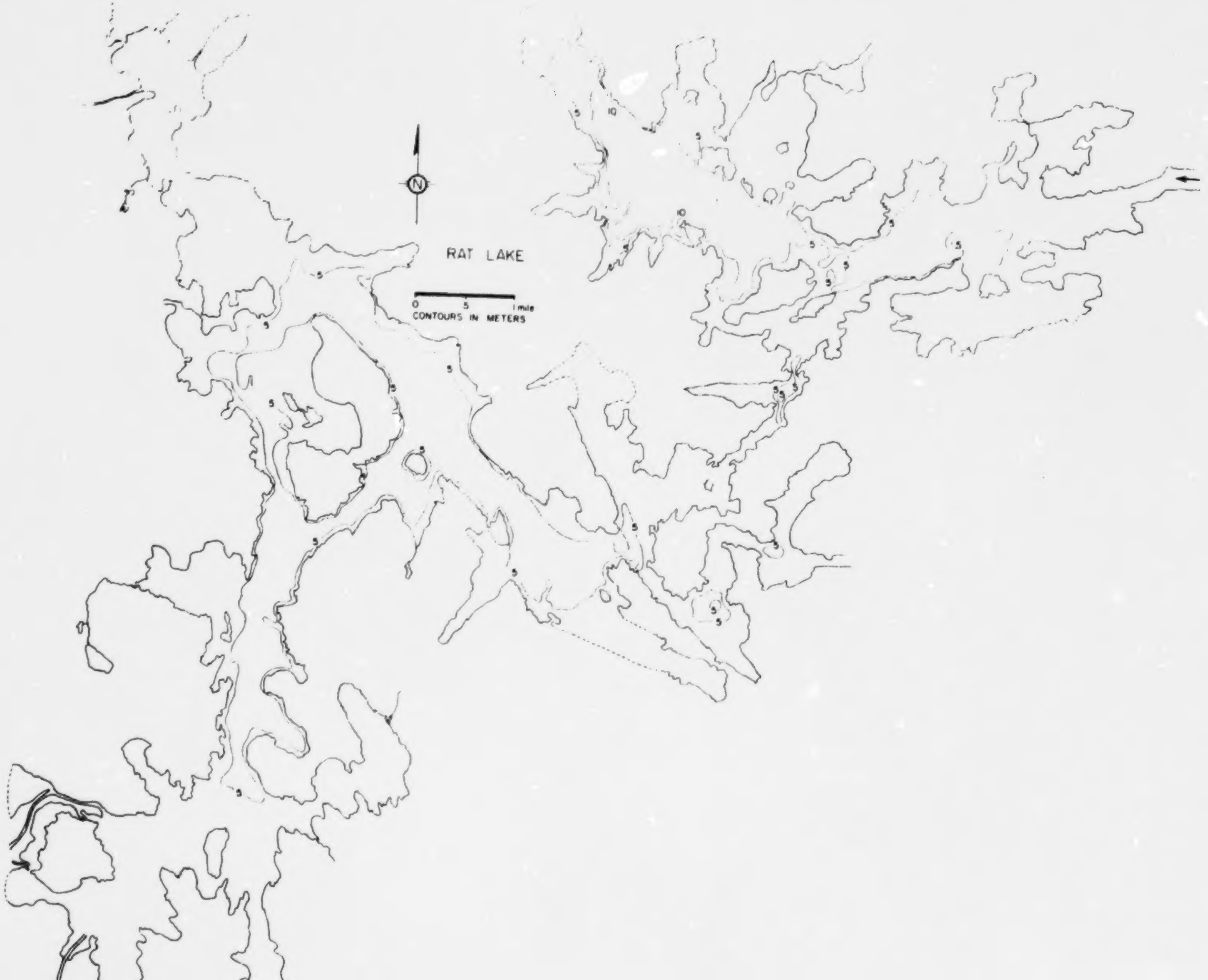
Figure 4. Bathymetric map of Pemichigamau Lake.

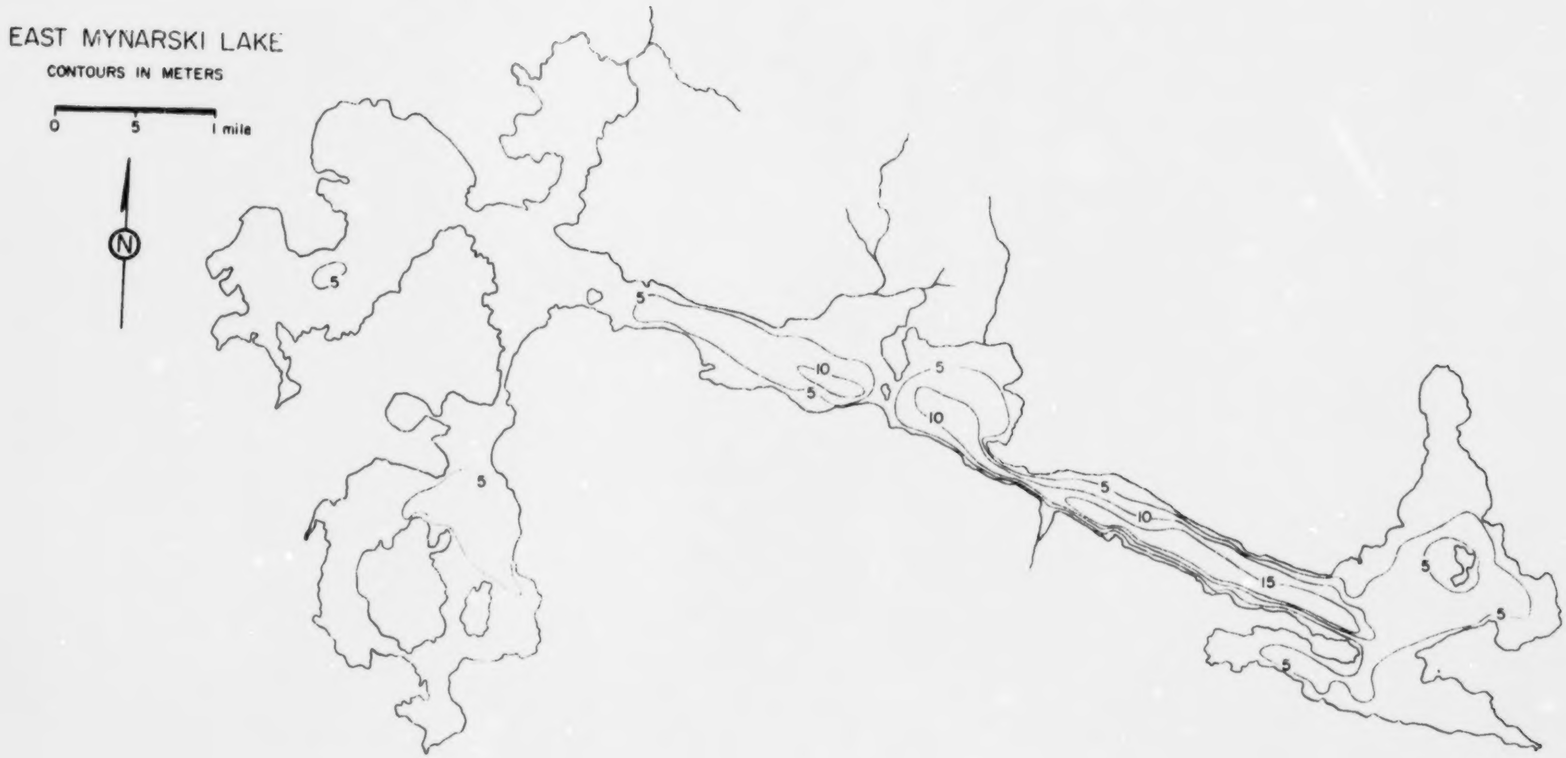

N
RAT LAKE
0 5 1 mile
CONTOURS IN METERS
5
10

Reading Rivers. It is connected to the rest of the lake via a narrow channel. The west part of the lake is V-shaped and divided into two basins by a large island. The Suwanee River flows into the west basin and the Rat River outflow is located on the southern corner of the central basin. The mean annual outflow of Rat Lake is approximately 870 cfs giving an exchange time of 136 days. The basin tends to a conical shape with a $\bar{z}/Zm$ ratio of 0.26.

The headwaters of the Reading River begin with East Mynarski Lake (Fig. 6). Being a headwater lake East Mynarski has a small drainage area (75 square miles) and a low outflow (40 cfs). This combination results in the longest exchange time of all the diversion route lakes (759 days). East Mynarski is the largest as well as the deepest of the three Mynarski lakes having a water area of 7.4 sq. miles and a mean depth of 13.6 feet. East Mynarski has an elongate shape with two basins joined by a deep channel resulting in an overall length of 8.3 miles. The shore development is intermediate being 4.27 or 4.83 including islands.

Central Mynarski Lake (Fig. 7) is smaller than East Mynarski having a water area of 4.4 square miles. It consists of a cross shaped basin with a large island in the center. This island gives Central Mynarski Lake the highest insulosity of any lake on the Rat-Burntwood diversion route (11.4%). Shore development is similar to East Mynarski Lake at 3.41 or 4.78 including islands. The $\bar{z}/Zm$ ratio is low (0.18) since the majority of the lake is shallow (mean depth 8.9 feet) with a deep hole of 49 feet on the east side.

West Mynarski (Fig. 8) is the smallest as well as the shallowest


EAST MYNARSKI LAKE
CONTOURS IN METERS
0
5
1 mile
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5
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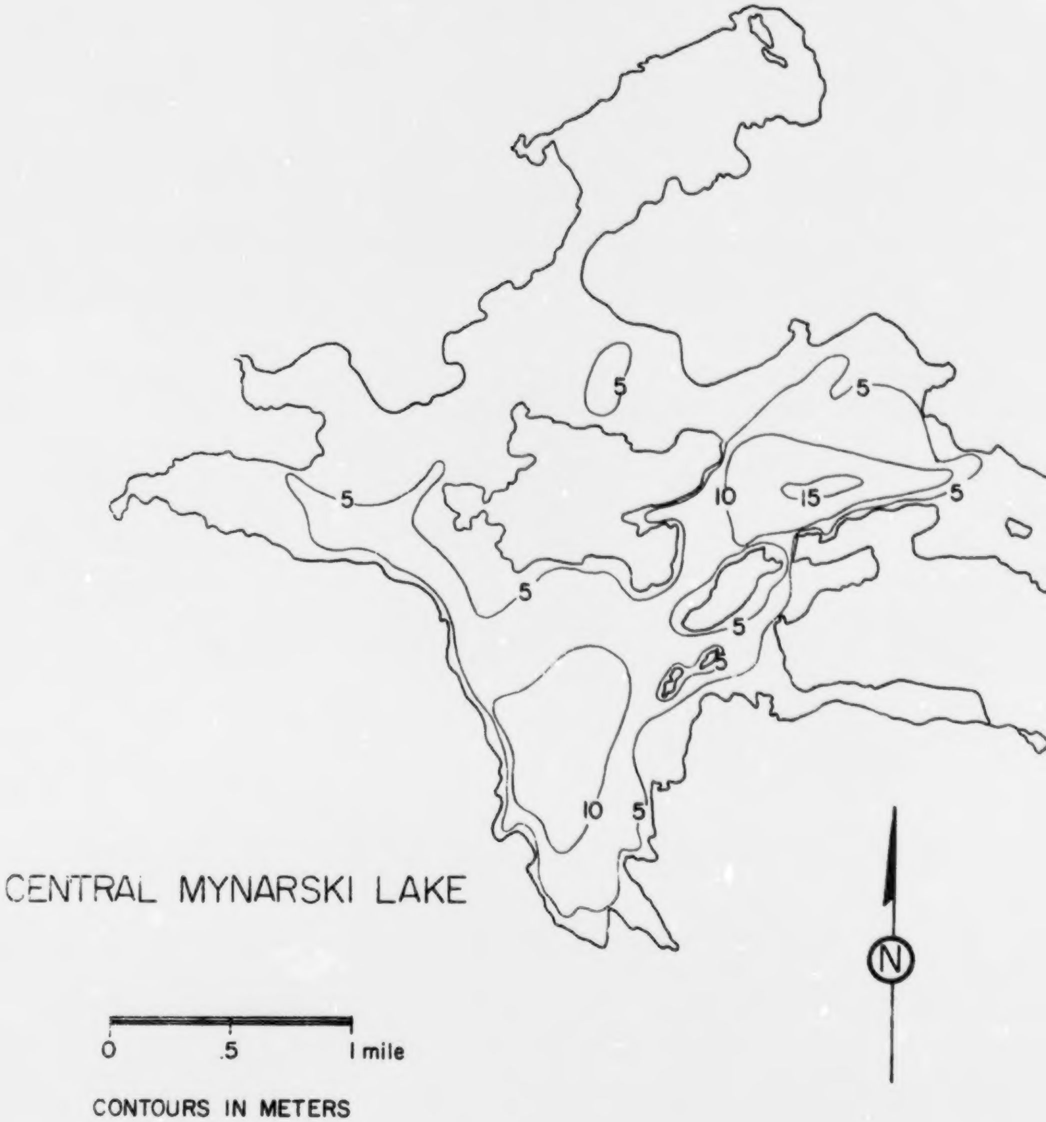
Figure 6. Bathymetric map of East Mynarski Lake.


CENTRAL MYNARSKI LAKE
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CONTOURS IN METERS
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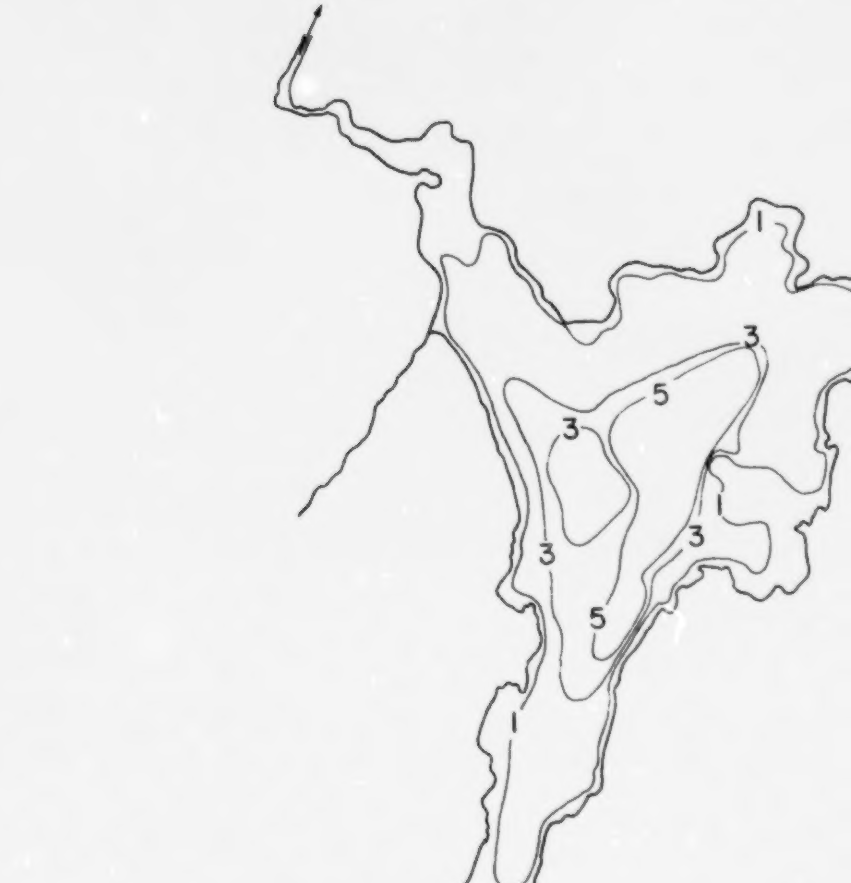
Figure 7. Bathymetric map of Central Mynarski Lake.


1
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WEST MYNARSKI LA
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1 m
CONTOURS IN METERS

Figure 8. Bathymetric map of West Mynarski Lake.

of the three Mynarski lakes. It has a water area of 2.4 square mi and a mean depth of 5.5 feet. The lake consists of one elongate b with four small islands. The shoreline is fairly regular giving i the lowest shore development of the Mynarski lakes (3.03 or 3.19 w islands). The total outflow for the Mynarski lakes is approximate 70 cfs.

Notigi Lake (Fig. 9), south of Rat Lake on the Rat River sy consists of two main basins and is approximately 9 miles long. Th basins have a combined water area of 5.8 square miles and an inter shore development of 3.81 or 4.02 with islands. Insulosity is ext low at 0.2%. The Rat River flows into the northeast side and out t southwest corner of the west basin. The east basin is separated by very narrow channel. The eastern region is the deeper of the two a receives the drainage from the Fold Lake area.

Wapisu Lake (Fig. 10) has an irregular shape similar to Rat Wapisu consists of three major basins in an elongate Z shape. The line is intricate as indicated by a high shore development (6.75 or including islands). The east basin is quite shallow with the other regions being deeper (up to 33 feet). The $\bar{z}/Zm$ ratio for Wapisu La is 0.33 which approximates a conical basin form. The overall excha time is slightly more than a month (42 days).

Threepoint Lake (Fig. 11) true to its name is the meeting po rivers; the Rat River, the Burntwood River, and the Footprint River. Rat and Burntwood Rivers flow into Threepoint from the west while th print River discharges from the north into the main channel of the l The other two channels between the two major islands are very shallo

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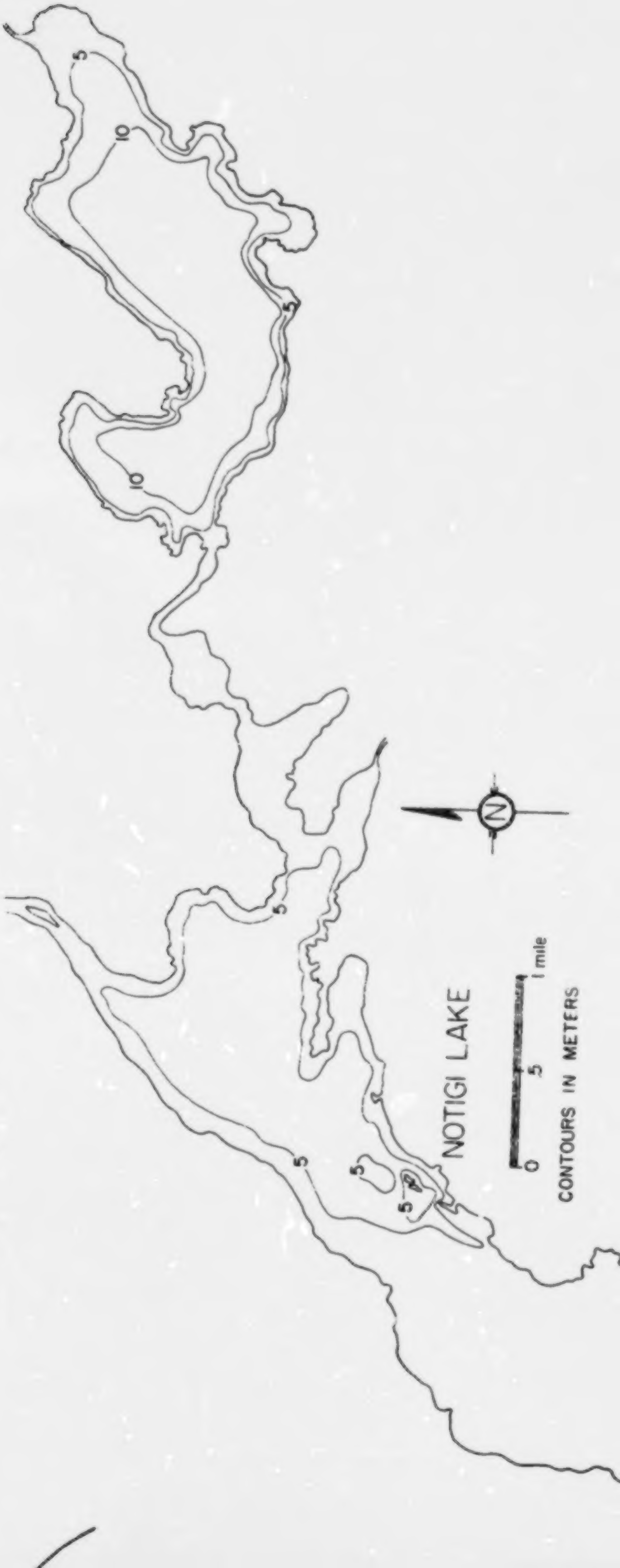
NOTIGI LAKE
CONTOURS IN METERS
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5
1 mile
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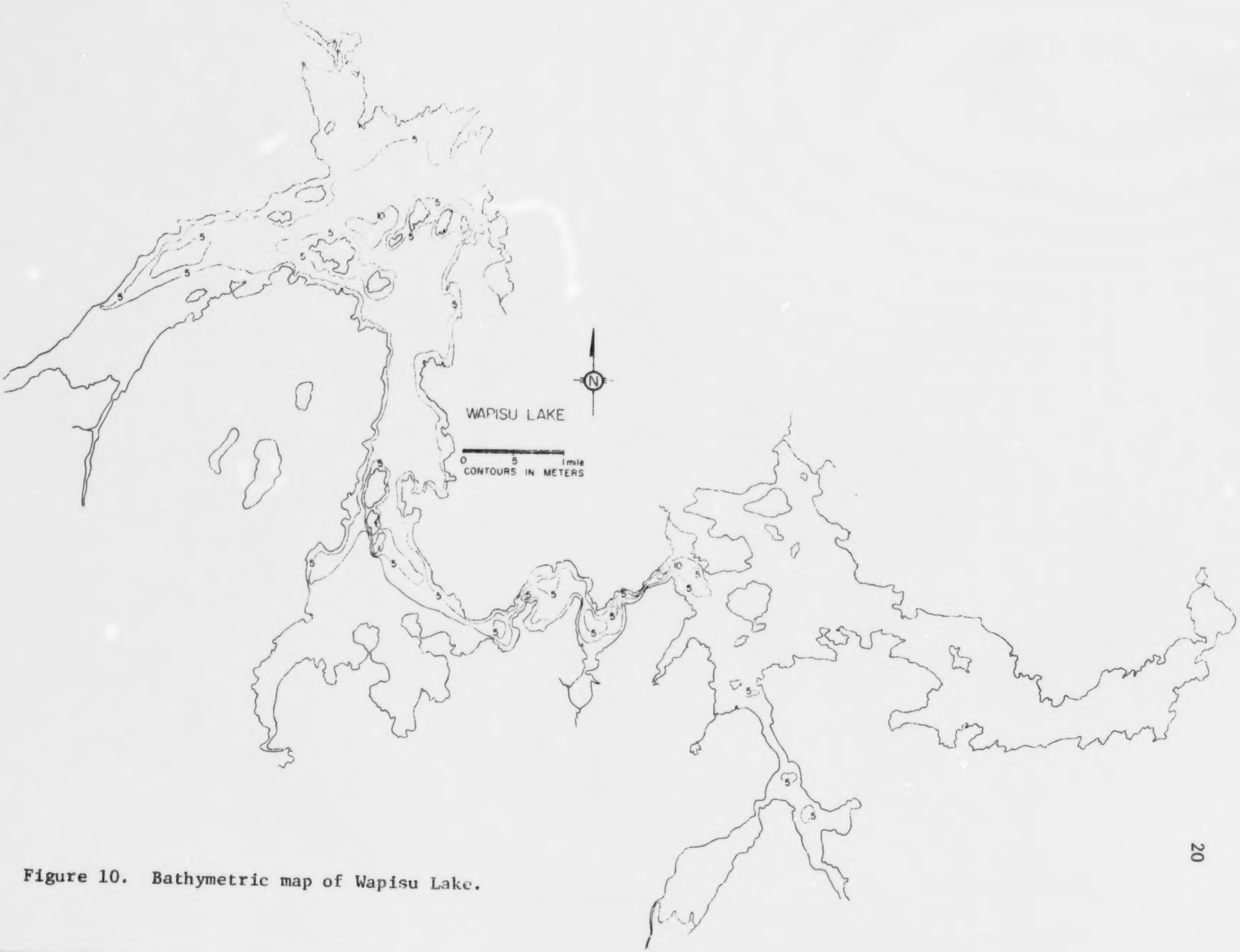
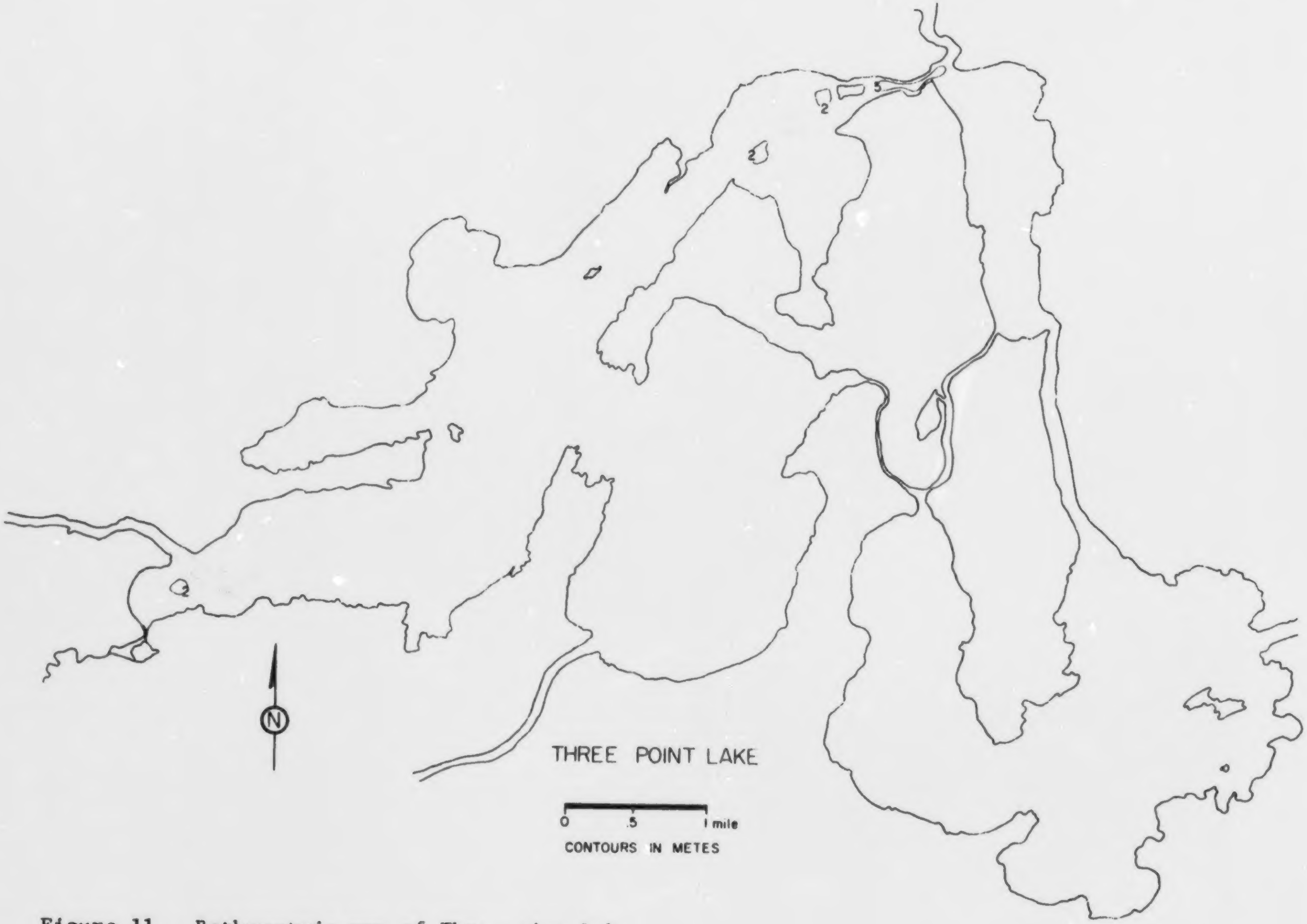

WAPISU LAKE
N
0
5
1mile
CONTOURS IN METERS
5
10

Figure 10. Bathymetric map of Wapisu Lake.


2
5
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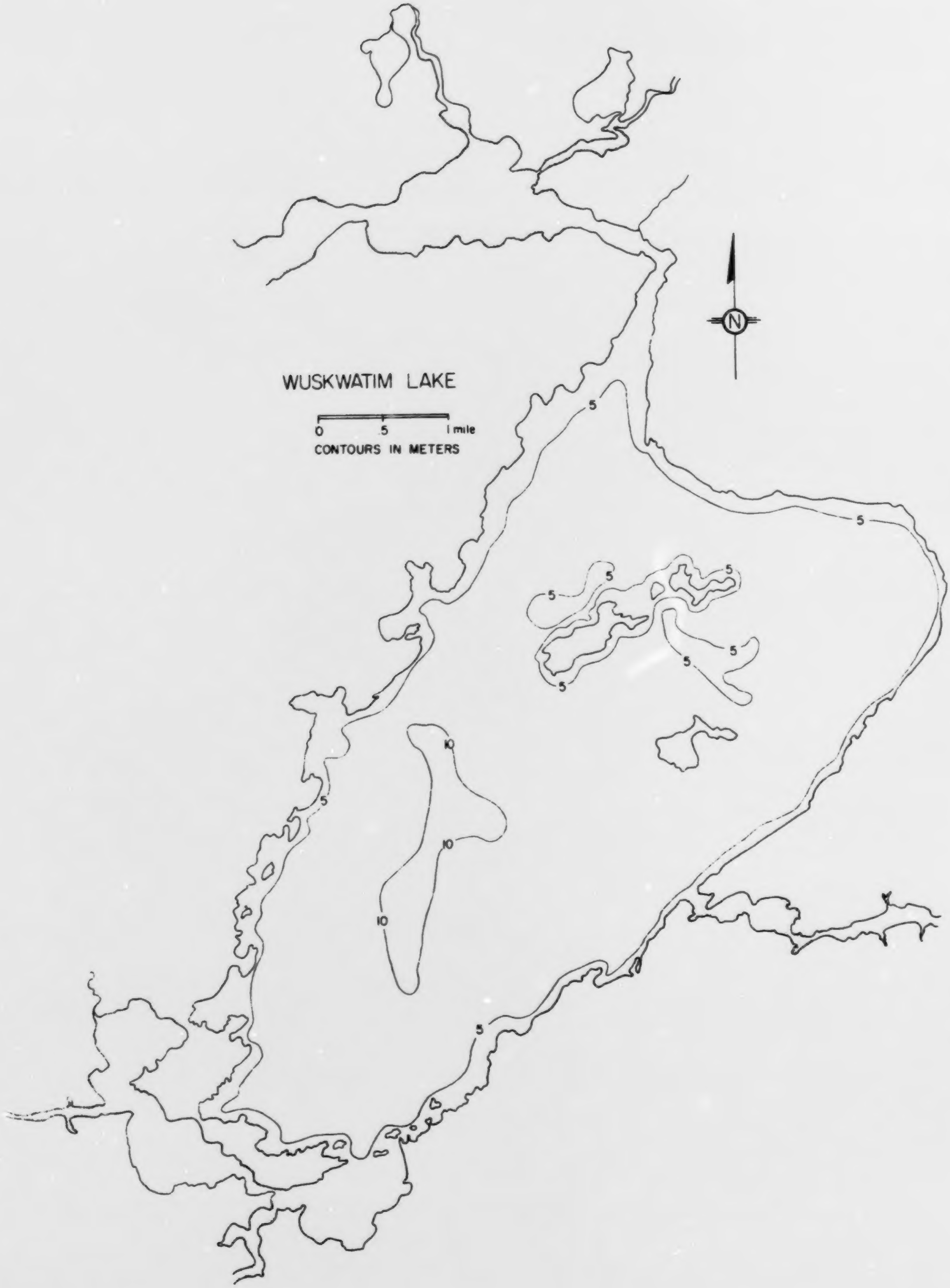
2
N
THREE POINT LAKE
0 .5 1 mile
CONTOURS IN METES

Figure 11. Bathymetric map of Threepoint Lake.

choked. For the main part Threepoint Lake is extremely shallow having a maximum depth of 23 feet and a mean depth of 2.3 feet. This maximum depth occurs in one very small area and the lake is generally less than 6 feet deep. The outflow is situated on the east side of the lake and has an approximate annual mean of 2,940 cfs. The increase outflow due to the Burntwood and Footprint Rivers and small volume give a rapid exchange time (5 days). The shoreline is quite regular and has a development of 2.75 or 3.88 including islands. Threepoint Lake has the second largest water area of the Rat-Burntwood River lakes at 18.2 square miles.

Wuskwatim Lake (Fig. 12) is the third largest of the lakes studied having a water area of 17.5 square miles. The lake has a uniform oval shape with few shoreline intricacies resulting in a low shore development (1.92 or 2.58 including islands). The contours are uniform and the basin has a $\bar{z}/Zm$ ratio of 0.52 indicating a U-shaped basin form. However, because Wuskwatim Lake received the fewest sounding transects (3) irregularities may have been missed. The Burntwood River flows into the north end of the lake and discharges midway along the east side.

Overall the Rat-Burntwood Lakes morphometrically fall into the ranges delineated by Koshinsky (1970) for Shield lakes. The lakes are glacial ice scour basins with $\bar{z}/Zm$ ratios ranging from 0.10 in Threepoint Lake to 0.52 in Wuskwatim Lake. Insulosity ranges from 0.2% in the smaller lakes to 8.2% in considerably larger Rat Lake. Shore development ranges from 1.56 in Issett to 8.76 in Rat Lake indicating an increased complexity attributable to Shield lakes of increasing size. However, the Rat-Burntwood Lakes are considered atypical Shield lakes.


WUSKWATIM LAKE
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.5
1 mile
CONTOURS IN METERS
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10
10
10
10
5
5

Figure 12. Bathymetric map of Wuskwatim Lake.

These lakes generally have rapid turnover times and are relatively shallow. This would tend to make these lakes isothermal in nature. Furthermore, these lakes are situated on a thick overburden of glaciolacustrine clays left from glacial Lake Agassiz. As a result the lakes have high nutrient loads from weathering of these clays and are more likely to be light-limited systems (Hecky, pers. comm.). The influence of these clays on shore development is illustrated on Threepoint Lake, Wuskwatim Lake, Issett Lake, Pemichigamau Lake, and Karsakuwigamak Lake. As previously discussed these lakes lay on areas that are physiographically classified as lacustrine clays. Their shorelines are generally more uniform due to the availability of sedimentary clays and silt for deposition over irregular bedrock areas and due to easier erosion of irregularities in overburden that might exist. Physically the lakes from Pemichigamau to Wapisu depict the influence of the Precambrian Shield with bedrock outcrops and till ridges. This is illustrated in higher shore developments. High shore development is important in nutrient-limited Shield lakes where it produces larger areas of littoral zone and hence higher productivity. However, high shore development may not be as important in these high-nutrient lakes.

Morphometry - post regulation:

The general morphometry of the Rat-Notigi and Wuskwatim Reservoirs is outlined in Table 4. The Rat-Notigi Reservoir is presently under construction and the Wuskwatim Reservoir is to be constructed at a later date.

The Rat-Notigi Reservoir will flood 158.5 square miles of land (Whidden 1973) giving a total water area of approximately 225.4 square

Table 4. General morphometric parameters of Rat-Notigi and Wuskwatim Reservoirs.

	Rat-Notigi Reservoir	Wuskwatim Reservoir
Total area km^2	661.8	581.2
(mi^2)	(255.5)	(224.4)
Water area km^2	583.8	523.2
(mi^2)	(225.4)	(202.0)
Maximum depth m	29.6	29.4
(ft)	(97.0)	(96.4)
Mean depth m	7.1	7.4
(ft)	(23.4)	(24.3)
Mean depth + Maximum depth	0.24	0.25
No. of islands	230	308
Island area km^2	78.0	58.0
(mi^2)	(30.1)	(22.4)
Insulosity %	11.8	10.0
Shore length total km	1918.5	1590.8
(mi)	(1192.1)	(988.5)
Lake outline km	1576.8	1205.4
(mi)	(979.8)	(749.0)
Shore length islands km	341.7	385.4
(mi)	(212.3)	(239.5)
Shore development	18.4	14.9
Shore development including islands	22.4	19.6
Volume m^3 x 10^6	4156.9	3873.2
(acre-feet x 10^6)	(3.37)	(3.14)
Mean annual outflow cfs	26852	31170
Exchange time days	63	51
Altitude m	259.1	247.0
(ft)	(850)	(810)

miles (Fig. 13). The reservoir, if raised to the 850 feet contour, will have an approximate volume of 3.37×10^6 acre-feet (Underwood-McLellan 1970). The shore development is extremely high at 18.4 or 22.4 including islands. This is not unusual since the flooding occurs over 120 miles of river beds and lakes. (The maps used for determination of shore length had a scale of 1 inch to the mile and were fitted with the 850 contour by Manitoba Hydro in 1967.) East Mynarski Lake will be unaffected by increased levels since it is at 868 feet. It can be used as a control for various processes that are to be monitored.

A second reservoir has been proposed with a damsite at Wuskwatim Rapids. If the forebay is raised to 810 feet, the flooded area will be 125.3 square miles (R.H. Lamont, pers. comm.) giving a water area of 202.0 square miles (Fig. 13) and a volume of 3.14×10^6 acre-feet. (The volume of the Wuskwatim Reservoir was calculated from the areas of contours on the Burntwood River Mapping Project maps at a scale of 1: 12,000.)

Even with no Wuskwatim development the levels of the lakes downstream of the Notigi damsite will be increased significantly. (Wapisu Lake + 14 feet, Threepoint + 15 feet, Footprint Lake + 11 feet, and Wuskwatim Lake + 13 feet - from Man. Water Res. Rat-Burntwood River profiles). This gives an approximate flooded area of 61.8 square miles to Wuskwatim Rapids and 6 square miles to the Manasan River at Thompson (R.H. Lamont, pers. comm.).

The flow throughout the Rat-Burntwood diversion route will be increased approximately 10x to a mean annual of 26,852 cfs. at the Notigi damsite (Man. Water Res. 1973).

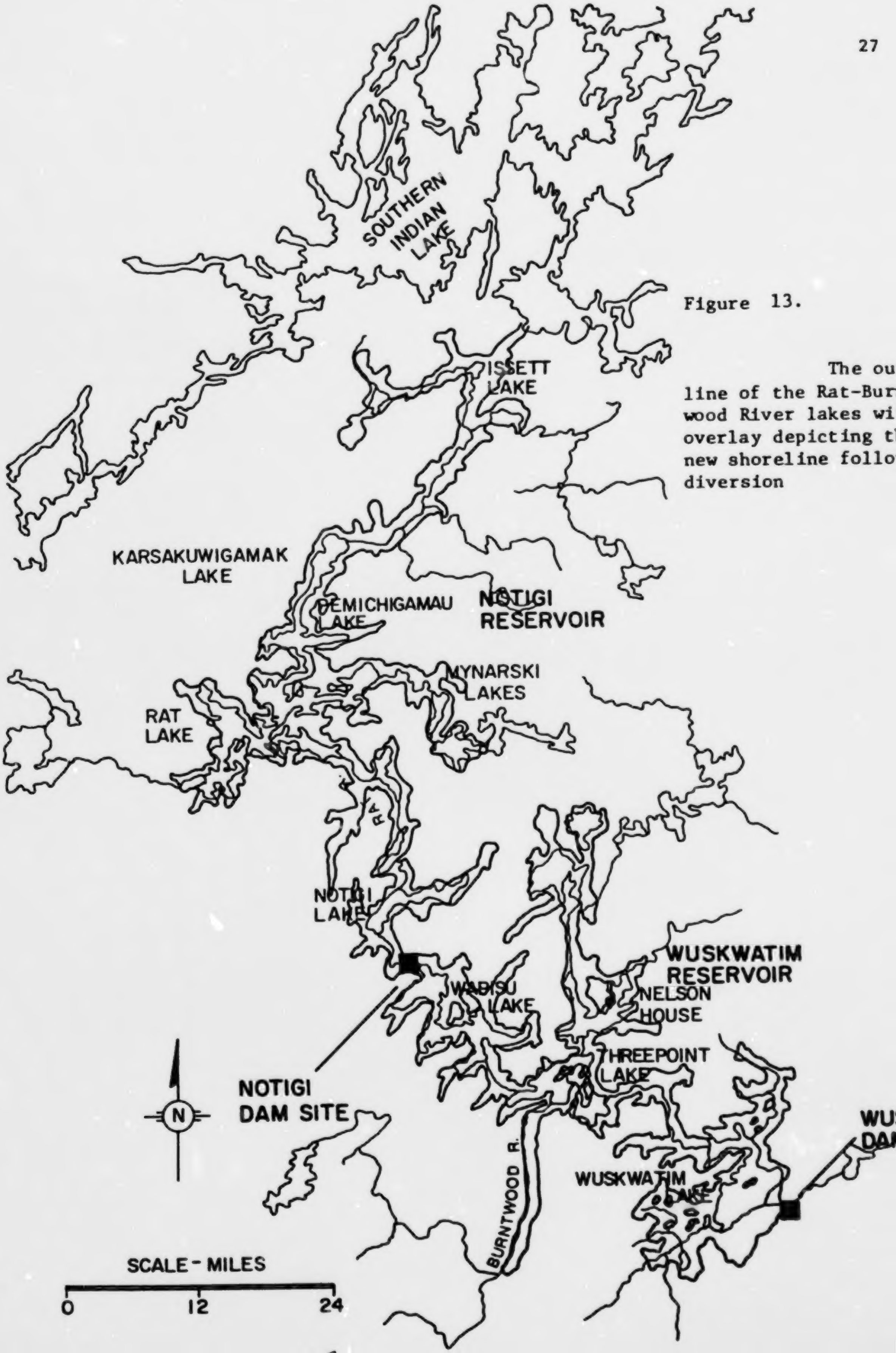
SOUTHERN INDIAN LAKE
ISSETT LAKE
KARSAKUWIGAMAK LAKE
DEMICHIGAMAU LAKE
NOTIGI RESERVOIR
MYNARSKI LAKES
RAT LAKE
RAT
NOTIGI LAKE
WUSKWATIM RESERVOIR
WAPISU LAKE
NELSON HOUSE
THREEPOINT LAKE
NOTIGI DAM SITE
N
BURNTWOOD R.
WUSKWATIM LAKE
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Figure 13.

The ou
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overlay depicting th
new shoreline follo
diversion

Since the general overburden is lacustrine clay severe erosion will introduce large quantities of suspended clay into the water. Furthermore the area is in a zone of discontinuous permafrost which will further aggravate shoreline and basin stabilization. Organic deposits flooded in the reservoirs will be a source of floating islands and debris.

The area most severely affected by current and level fluctuations will be downstream of the Notigi control structure. These fluctuations (see Tables 5 and 5A for flow differences at Wuskwatim Rapids) will further limit shoreline stabilization and contribute to erosion and silting problems within the system.

Table 5. Historic mean monthly flow (cfs) data at Wuskwatim Rapids, 1928-1966. (Man. Water Resources 1973)

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Minimum	293	260	242	264	1967	1578	493	920	360	482	545	425	242
Mean	1080	914	800	894	5933	7715	5991	4012	3626	2801	2172	1514	3121
Maximum	2202	1935	1778	2563	10733	15746	11776	11309	9654	6875	4438	2730	15746

Table 5a. Mean monthly flows (cfs.) after impoundment and diversion.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Minimum	17042	7990	17767	7718	10841	31041	34000	32736	24683	25060	19876	17781	7718
Mean	29457	28295	27429	26519	32120	33991	34000	33937	33384	32562	32056	30286	31170
Maximum	32461	32405	32119	32258	34000	34000	34000	34000	34000	34000	34000	33145	34000

LOWER CHURCHILL LAKES

Geography:

The lower Churchill River lakes studied include Partridge Lake, Northern Indian Lake, and Fidler Lake (Fig. 1B). They are situated immediately downstream of Southern Indian Lake approxima 115 miles north of Thompson at 96°50' - 98°05'W by 57°10' - 57°25 Wood Lake, a nearby Shield lake, was also studied for comparative purposes.

The lakes are located entirely on the Precambrian Shield, Partridge Breast, Northern Indian, and Fidler Lakes receive the m of their flow from Missi Rapids (35,700 cfs) on Southern Indian L fore,they are riverine lakes with much lower exchange times than Shield lakes.

The bedrock formations of the area consist mainly of grani rocks with mixed and sedimentary gneisses. Near Partridge Breast there is also a band of copper bearing metavolcanic rocks (Davies The area is generally rolling ice-scoured upland with few bedrock crops and till ridges. The overburden consists of a relatively t layer of glacio-lacustrine clay with a surface layer of grey-wood podzol.

The lakes are classified as in an area of discontinuous per frost (Brown 1970). Underwood & McLellan (1970) states that perma is present in all clay materials except in those on ridgetops and

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present in most organic deposits. The vegetation os the a
primarily of black spruce with jackpine on the sand soils.
mosses are found in the marsh-muskeg areas.

The climate is cold continental with a mean annual
23°F. and a mean annual precipitation of 15 inches of which
snow (Weir 1960). Freezeup for lakes and bays occurs arou
and for rivers around November 10. Breakup occurs around
lakes and bays and around May 20 for rivers.

There are no major transportation routes near the l
are only accessible by air. None of the lakes have a perm
however, a summer commercial fishery is located on Norther
Fidler Lakes. Partridge Breast Lake has not been fished i
years.

Morphometry - present conditions:

The general morphometry of the lakes is outlined in
The drainage areas given include all inflows into each lak
of the Churchill River.[1] Flushing times were calculated a
mixing of the water throughout each lake. The flow patter
lakes is evident from Fig. 14.

Partridge Breast Lake (Fig. 15) is the first lake d
Missi Rapids. It is approximately 9.3 miles long. With a
9.2 square miles it is the smallest of the Churchill River
Partridge Breast is generally a widening of the river chan

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[1] Drainage areas found by dot area grid on 1:250,000 Nat
Topographical maps.

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Table 6. General morphometric parameters of three lower Churchill River lakes and Wood Lake.

	Partridge Breast Lake	Northern Indian Lake	Fidler Lake	Wood Lake
Total area km^2	28.7	204.5	39.0	24.5
(mi^2)	(11.1)	(78.9)	(15.1)	(9.5)
Water area km^2	23.8	144.7	38.8	22.9
(mi^2)	(9.2)	(55.9)	(15.0)	(8.8)
Maximum depth m	22.5	58.0	19.0	32.0
(feet)	(73.8)	(190.3)	(62.3)	(105.0)
Mean depth m	6.3	5.7	3.0	9.0
(feet)	(20.7)	(18.6)	9.8	(29.4)
Mean depth ÷ Maximum depth	0.28	0.10	0.16	0.28
No. of islands	14	182	5	9
Island area km^2	4.9	59.8	0.2	1.6
(mi^2)	(1.9)	(23.1)	(0.1)	(0.6)
Insulosity %	17.1	29.2	0.5	6.5
Shore length total km	120.1	464.8	59.5	65.0
(mi)	(74.6)	(288.8)	(37.0)	(40.4)
Lake outline km	94.6	229.0	56.4	52.1
(mi)	(58.8)	(142.3)	(35.0)	(32.4)
Shore length islands km	25.4	235.8	3.1	12.9
(mi)	(15.8)	(146.5)	(1.9)	(8.0)
Shore development	4.99	8.64	2.56	3.08
Shore development including islands	6.33	10.90	2.68	3.84
Drainage area km^2	284.9	8948.5	453.3	373.0
(mi^2)	(110.0)	(3455.0)	(175.0)	(144.0)
Mean annual outflow cfs	35,894	37,134	37,223	66
Exchange time days	1.7	9.0	1.3	862.1
Altitude m	244.9	235.9	231.5	–
(feet)				

No. of transects	28	58	19	43

Table 7. Areas of contours and volume of three lower Churchill River lakes and Wood Lake.

	Partridge Breast Lake	Northern Indian Lake	Fidler Lake	Wood Lake
Water area km^2 (0 m contour)(mi^2)	23.8 (9.2)	144.7 (55.9)	38.8 (15.0)	22.9 (8.8)
Area of 2 m contour km^2 (mi^2)	-	-	20.5 (7.9)	-
Area of 5 m contour km^2 (mi^2)	13.6 (5.3)	72.3 (27.9)	5.1 (2.0)	13.1 (5.0)
Area of 10 m contour km^2 (mi^2)	4.6 (1.8)	44.1 (17.0)	1.5 (0.6)	7.2 (2.8)
Area of 15 m contour km^2 (mi^2)	1.0 (0.4)	-	0.6 (0.2)	-
Area of 20 m contour km^2 (mi^2)	0.03 (0.01)	14.7 (5.7)	-	3.1 (1.2)
Area of 30 m contour km^2 (mi^2)	-	4.4 (1.7)	-	0.6 (0.2)
Area of 40 m contour km^2 (mi^2)	-	1.5 (0.6)	-	-
Area of 50 m contour km^2 (mi^2)	-	0.2 (0.1)	-	-
Volume m^3 x 10^6 (acre-feet x 10^6)	150.74 (0.122)	817.55 (0.663)	115.0 (0.093)	204.84 (0.166)

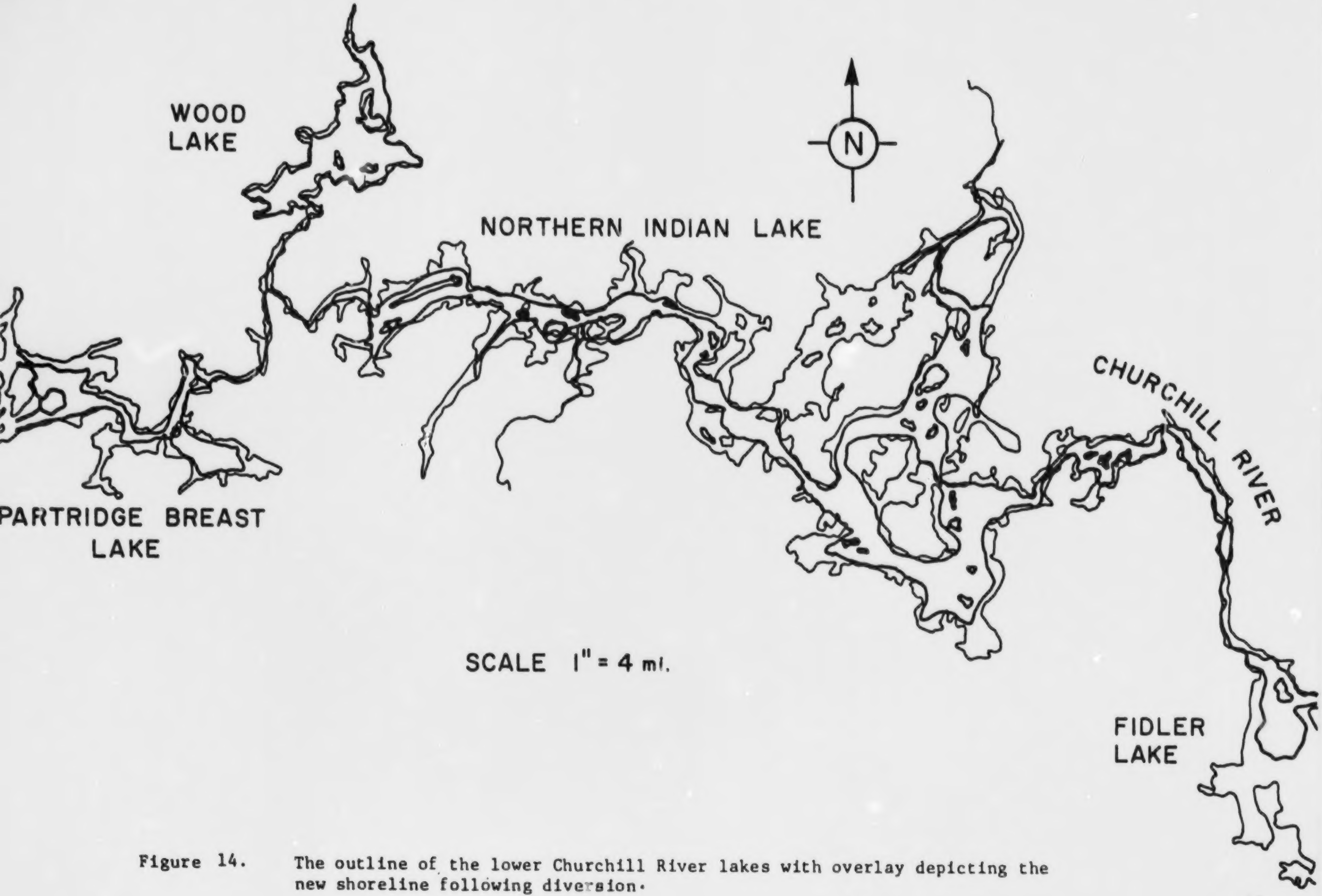
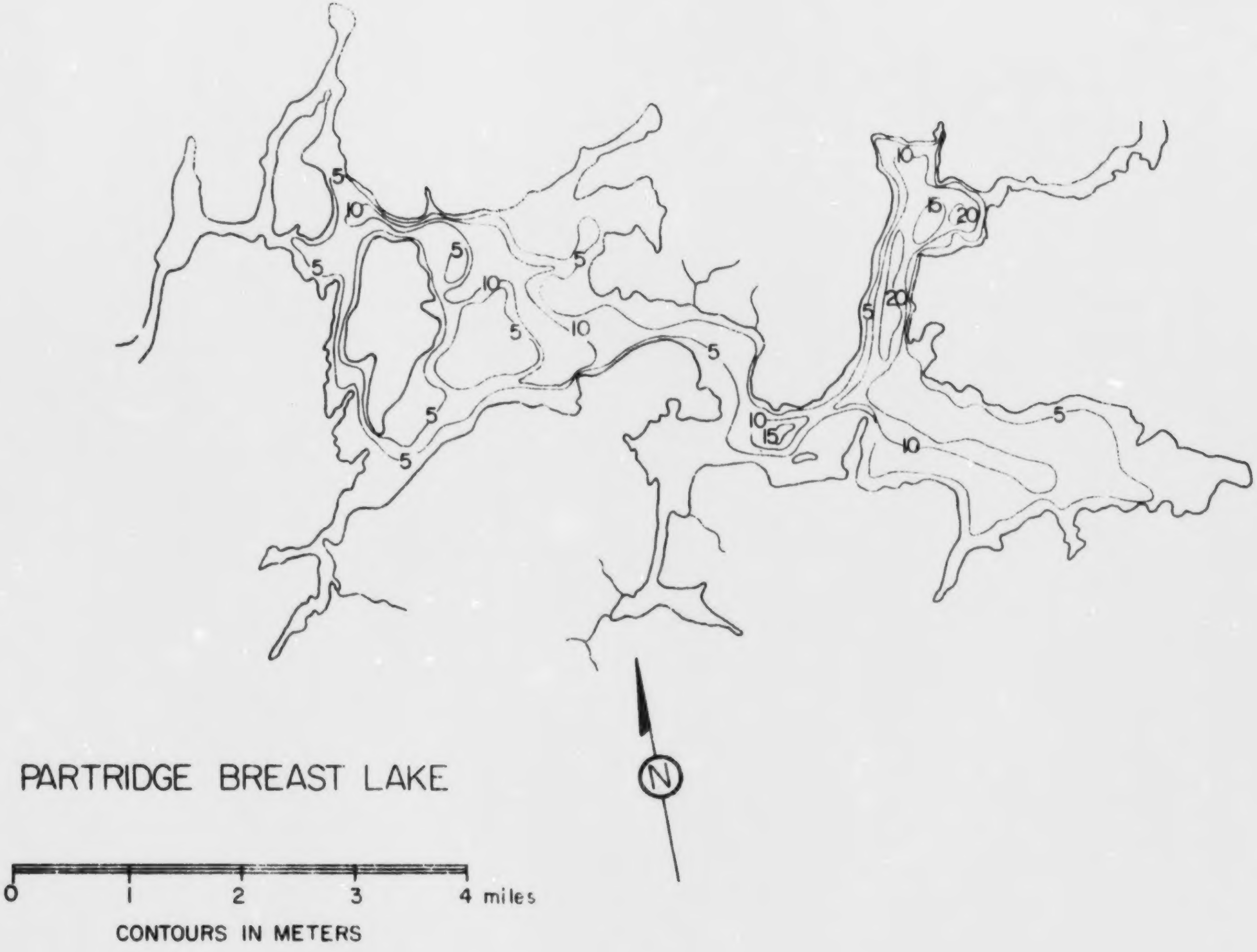

WOOD LAKE
NORTHERN INDIAN LAKE
CHURCHILL RIVER
N
PARTRIDGE BREAST LAKE
SCALE 1" = 4 mi.
FIDLER LAKE

Figure 14. The outline of the lower Churchill River lakes with overlay depicting the new shoreline following diversion.


PARTRIDGE BREAST LAKE
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1
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4 miles
CONTOURS IN METERS
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5
10
15
20

Figure 15. Bathymetric map of Partridge Breast Lake.

extensions. The shoreline is fairly intricate resulting in a shore development of 5.0 or 6.3 including islands. The $\bar{z}/Zm$ ratio is 0.28 which approximates a conical basin form.

Northern Indian Lake is the second lake downstream of Missi Rapids (Fig. 16). With a water area of 55.9 square miles and a length of 21 miles it is the largest of the lower Churchill River lakes studied. Since the Gauer and Oldman Rivers discharge into Northern Indian Lake it has by far the largest drainage area of the lakes studied (3,455.0 sq. mi.). Northern Indian Lake also has the most intricate shoreline and highest shore development (8.6 or 10.9 including islands) of the lakes in this region.

Fidler Lake (Fig. 17) is the furthest lake downstream of the lakes studied. It has a larger water area than Partridge Breast Lake (15.0 sq. mi.). However, Fidler is shallow with a mean depth of 9.8 feet, due in part to the unique shape of the lake. Fidler consists of a very shallow but large basin to the south and a main river channel flowing through the north. The southern reaches of this basin receive a small inflow from the Settee Lake region, however, during the summer this becomes nearly stagnent. Therefore, the assumption of total mixing for exchange time is more incorrect for this lake than the others. Fidler has a very regular shoreline with very few islands resulting in a low shore development (2.56 or 2.68 with islands).

Wood Lake (fig. 18) lies immediately north of the Churchill River between Partridge Breast Lake and Northern Indian Lake. The outflow of Wood Lake into the Churchill River is 66 cfs.[1] This low flow results

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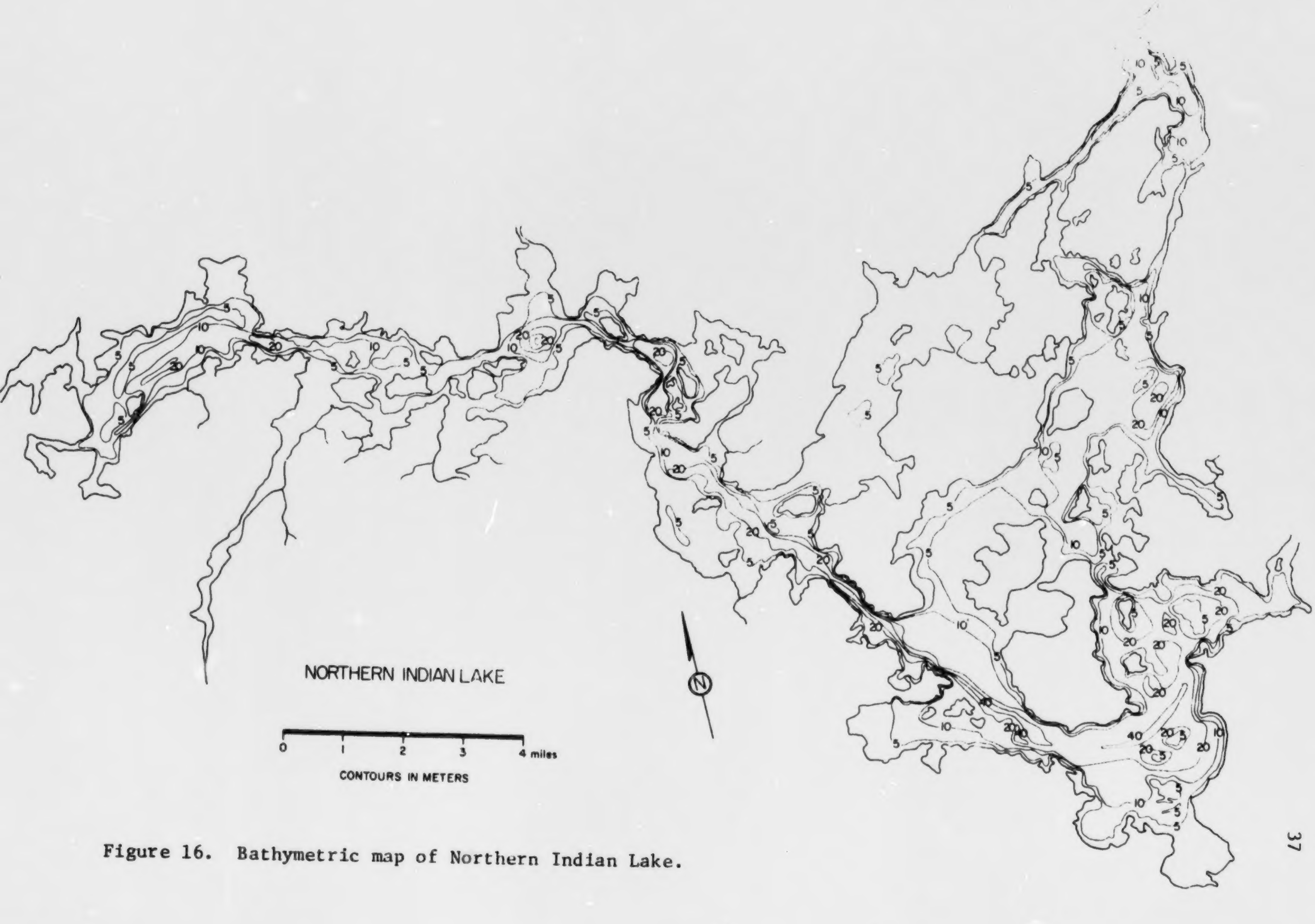
[1] The outflow was calculated from the size of the Wood Lake drainage basin relative to the overall drainage basin of Northern Indian Lake using the modified historic residual outflow of Northern Indian after regulation (estimated by Man. Water Res. 1973).


NORTHERN INDIAN LAKE
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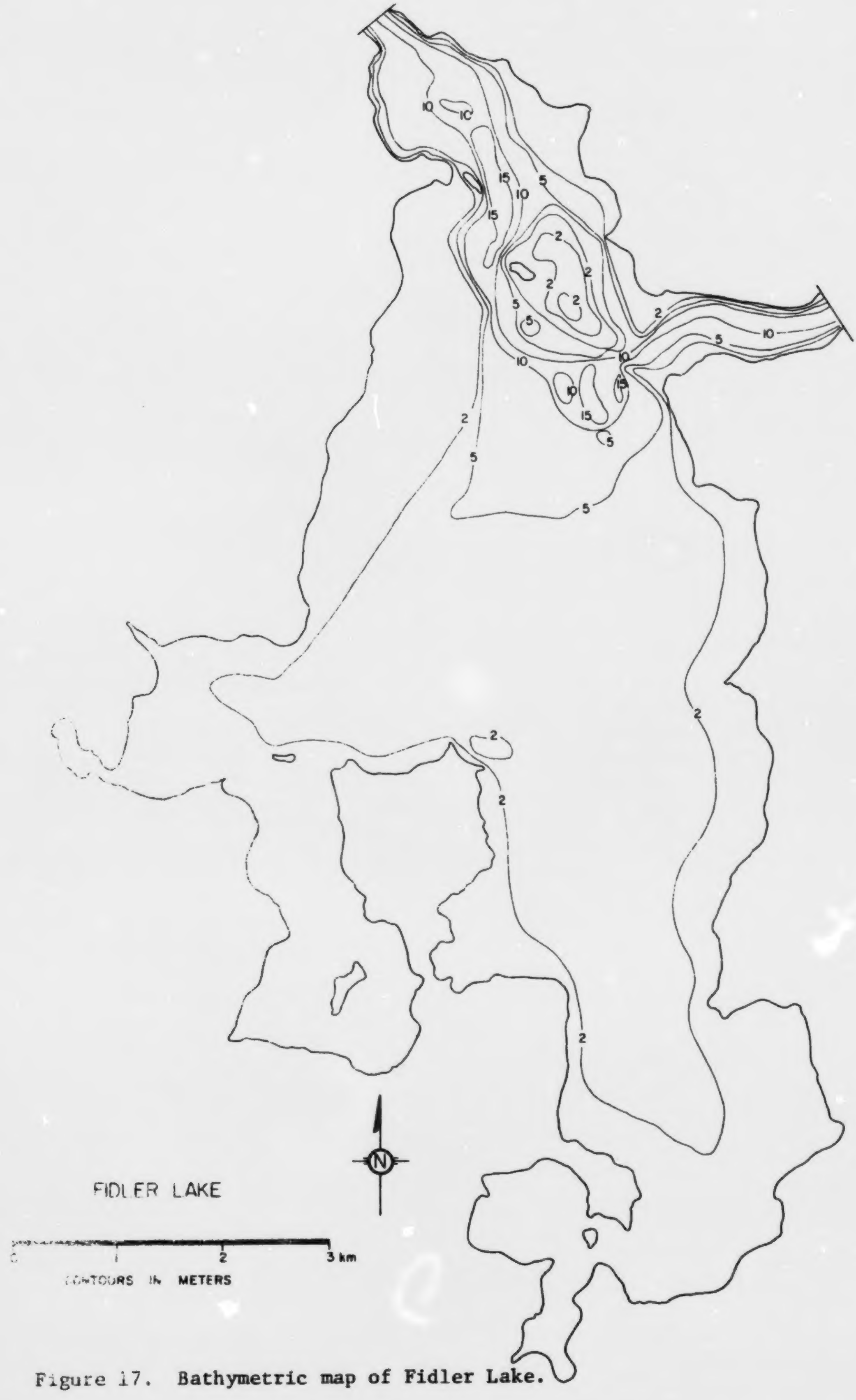
4 miles
CONTOURS IN METERS

Figure 16. Bathymetric map of Northern Indian Lake.


10
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15
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10
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2
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5
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15
10
15
5
2
5
5
2
2
2
2
N
FIDLER LAKE
0
1
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3 km
CONTOURS IN METERS

Figure 17. Bathymetric map of Fidler Lake.

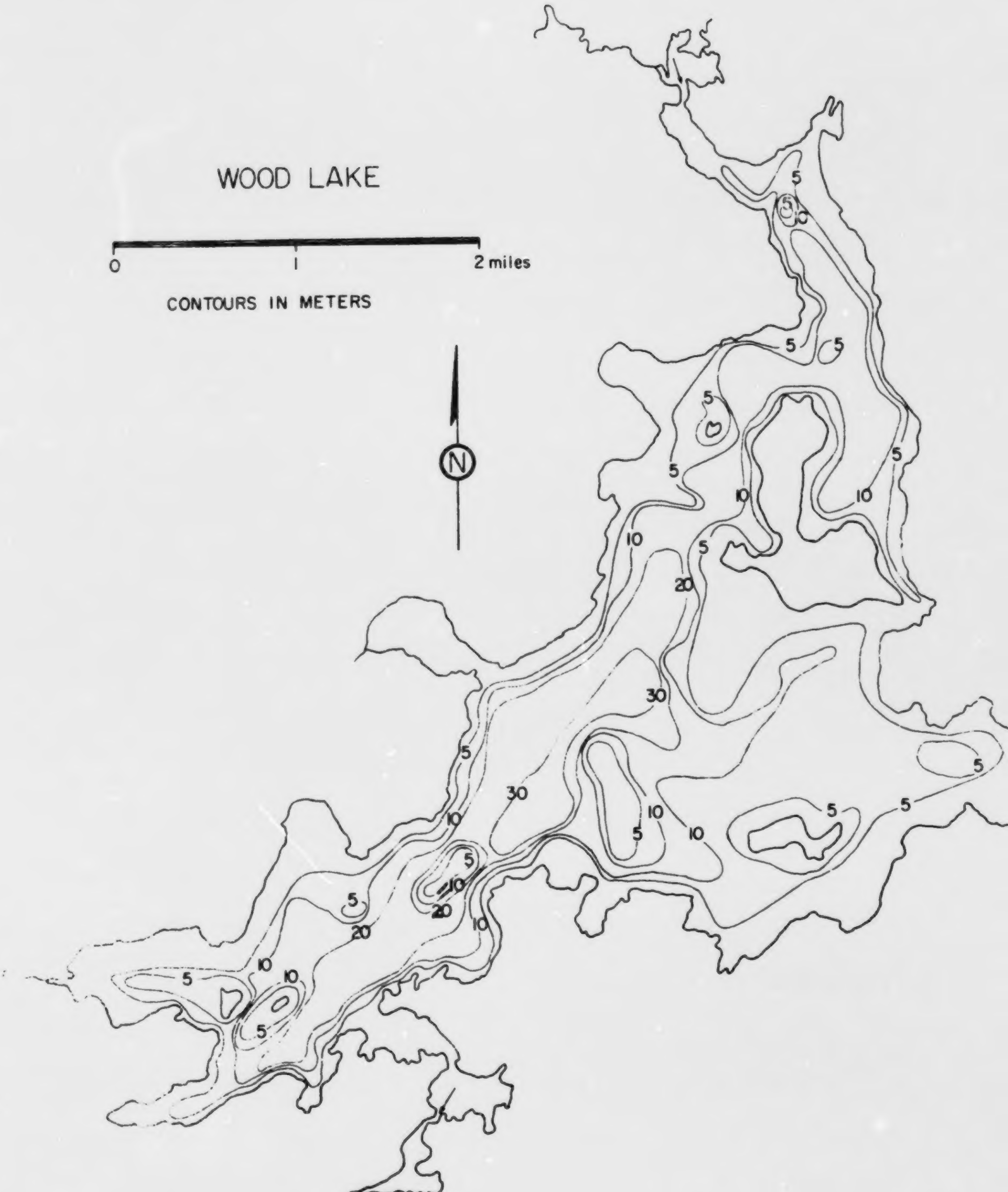

WOOD LAKE
0
1
2 miles
CONTOURS IN METERS
N
5
10
20
30

Figure 18. Bathymetric map of Wood Lake.

in a high turnover time for this lake (862 days) when compared to the riverine Churchill River lakes. Wood Lake has a water area of 8.8 square miles and is approximately 6.7 miles long. It has a relatively low shore development of 3.08 or 3.91 including islands. The lake has a deep channel (105 feet) along the west side.

Table 8 is a general morphometric comparison of the lower Churchill River lakes with other Churchill River lakes on the Shield. These lakes are all riverine and the high Churchill River inflow exerts by far the predominate effect on chemistry, biology, and perhaps morphometry. The basins likely were glacial scoured areas deepened by the Churchill River flows as evidenced by the deep main channels. The $\bar{z}/Zm$ ratio (0.33) indicates a basically conical basin form (Koshinsky 1970). This ratio is low in the lower Churchill River lakes, lower than Rawson's Churchill River lakes (1960), but consistent with Opachuanau studied by Cleugh et al. (1974). This tends to indicate the peripheral, shallow, littoral zone of the lower Churchill River lakes is large and can potentially influence to a greater degree the biology of these lakes. This will be particularly true in the larger shallow arms and bays of these lakes. The insulosities and shore development vary widely but are generally similar for Churchill River lakes of similar size.

Morphometry - post regulation

The general morphometry after regulation of Partridge Breast Lake, Northern Indian Lake, and Fidler Lake has been summarized in Table 9. By diverting the Churchill River with a channel at South Bay and a control structure at Missi Rapids, the flow of the Churchill River will be con-

Table 8. A morphometric comparison of the lower Churchill River lakes with four lakes in Churchill River system (after Rawson 1960 and Cleugh et al., 1974).

	Partridge Breast Lake	Northern Indian Lake	Fidler Lake	Mountain Lake	Nistowiak Lake	Drinking Lake	Opachuanau Lake
Water area km^2	23.8	144.7	38.8	53.9	28.2	16.3	77
(mi^2)	(9.2)	(55.9)	(15.1)	(20.8)	(10.9)	(6.3)	(30)
Area of islands km^2	4.9	59.8	0.2	7.3	2.3	1.8	2.3
(mi^2)	(1.9)	(23.1)	(0.1)	(2.8)	(0.9)	(0.7)	(0.9)
No. of islands	14	182	5	117	59	22	84
Insulosity %	12.5	29.2	0.5	11.9	7.5	10.0	2.9
Maximum depth m	22.5	58.0	19.0	34	21.5	37.0	26.0
(ft)	(73.8)	(190.3)	(62.3)	(113)	(71)	(123)	(85.3)
Mean depth m	6.3	5.7	3.0	11.5	10.1	12.2	5.3
(ft)	(20.7)	(18.6)	(9.8)	(38)	(33)	(40)	(17.4)
Mean depth ÷ Maximum depth	0.28	0.10	0.16	0.34	0.46	0.33	0.20
Lake outline km	94.6	229.0	56.4	156	64.4	74.0	141.5
(mi)	(58.8)	(142.3)	(35.0)	(97)	(40)	(46)	(87.9)
Shore length islands km	25.4	235.8	3.1	93	30.6	12.9	13.5
(mi)	(15.8)	(146.5)	(1.9)	(58)	(19)	(8)	(8.4)
Shore development	4.99	8.64	2.56	6.0	3.4	5.2	4.5
Shore development including islands	6.33	10.90	2.68	9.6	5.0	6.5	5.0
Altitude m	244.9	235.9	231.5	339.9	338.7	334.5	254.9
(ft)	(803.5)	(774.0)	(759.6)	(1115)	(1111)	(1097)	(836)
Drainage area km^2	284.9	8935.5	453.3	-	-	-	-
(mi^2)	(110.0)	(3450.0)	(175.0)				

Table 9. General morphometric parameters of lower Churchill River lakes after regulation with percentage change.

	Partridge Breast Lake		Northern Indian Lake		Fidler Lake	
		% change		% change		% change
Total area km^2	21.5	- 25	99.2	- 51	10.0	- 74
(mi^2)	(8.3)		(38.3)		(3.9)	
Water area km^2	14.5	- 39	87.8	- 39	9.3	- 76
(mi^2)	(5.6)		(33.9)		(3.6)	
Island area km^2	7.0	+ -2	11.4	- 81	0.7	+ 71
(mi^2)	(2.7)		(4.4)		(0.3)	
No. of islands	7		63		2	
Insulosity %	32.5		11.5		7.7	
Shore length total km	59.9	- 50	235.0	- 49	19.9	- 67
(mi)	(37.2)		(146.0)		(12.4)	
Lake outline km	44.1	- 53	165.4	- 28	13.6	- 76
(mi)	(27.4)		(102.8)		(8.5)	
Shore length of islands km	15.8	- 38	69.6	- 71	6.3	+103
(mi)	(9.8)		(43.2)		(3.9)	
Shore development	3.27		4.98		1.26	
Shore development including islands	4.43		7.07		1.84	
Volume m^3 x 10^6	106.9	- 29	414.5	- 49	34.0	- 70
(acre feet 10^6)	(0.087)		(0.336)		(0.028)	
Mean annual outflow cfs	9,043		10,336		10,434	
Mean depth m	7.4	+ 18	4.7	- 18	3.7	+ 23
(ft)	(24.3)		(15.4)		(12.1)	
Maximum depth m	19.6		55.0		15.9	
(ft)	(64.3)		(180.3)		(52.2)	
Exchange time days	4.8	+182	16.4	+ 82	1.3	-
Altitude m	242.1		232.9		229.3	
(ft)	(794)		(764)		(752)	

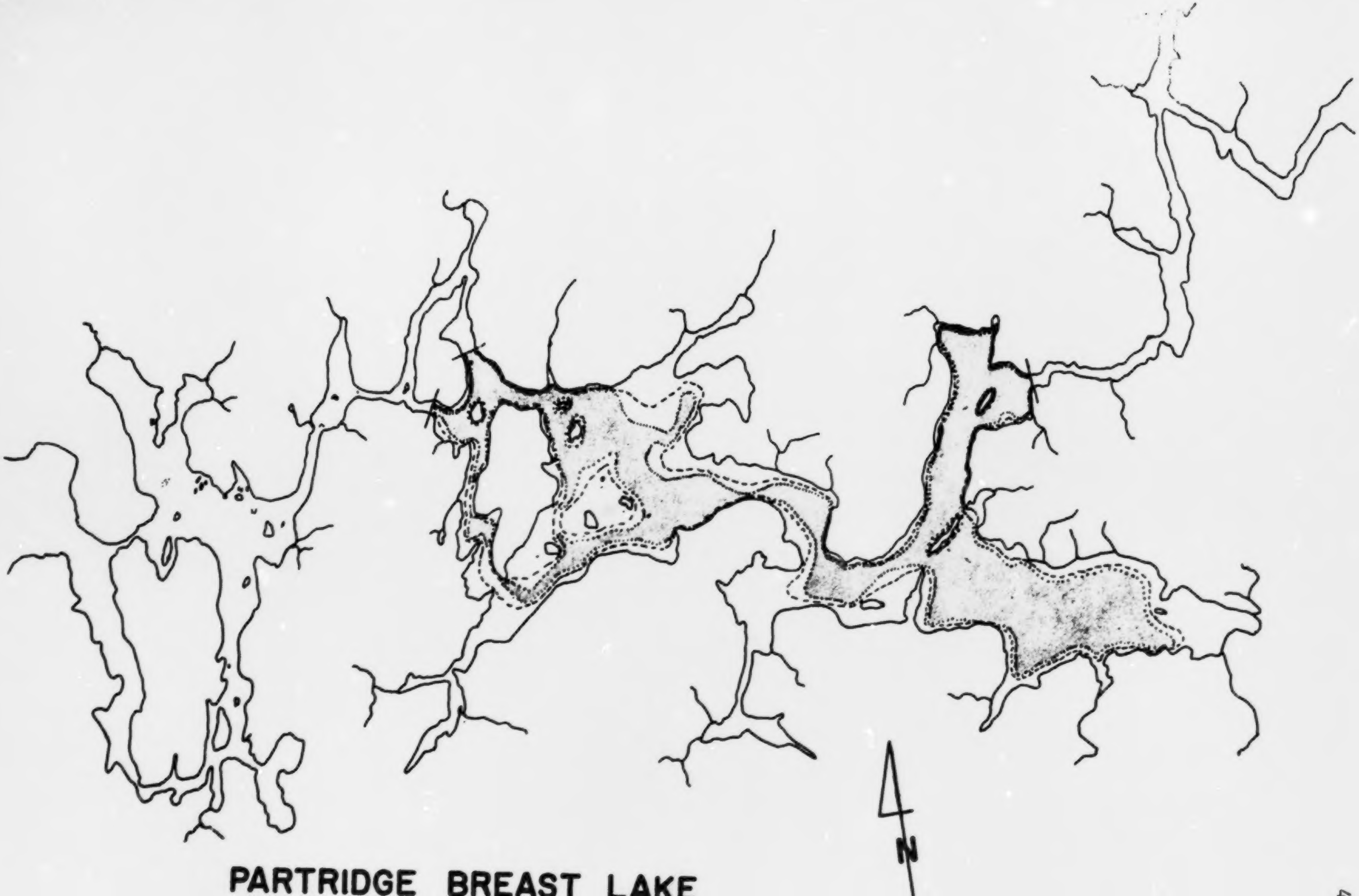
siderably reduced resulting in a decrease in the levels of the low Churchill lakes.

Maps of the lakes showing the lower water conditions have b prepared (see Figs. 14, 19-21). The individual maps have the aver level indicated by a dashed line and the absolute minimum levels s The absolute maximum levels are approximately one foot lower than normal maximum and the original lake outline can be used to approx these levels. The levels and flows used in the calculation of the morphological parameters and used in drawing the maps are projecte published by Manitoba Water Resources (1973).

Wood Lake is at a high enough elevation that it will be una by any drawdown on the Churchill River.

Partridge Breast Lake (Fig. 19) will be lowered by approxim 9.8 feet to a mean annual level of 793.7 feet. The water area and will be reduced 39% and 29% respectively. However, the mean depth increases 18% since the shallow periphery of the lake is eliminate the water recedes into the main river channel. Shore development decrease from 4.99 to 3.27 as less distance is required to enclose lake and insulosity increases 15.4% as more land is exposed by the receding water. Exchange time increases, but not significantly

Northern Indian Lake (Fig. 20) will be lowered by 10.3 feet a mean annual level of 763.7 feet. The water area and volume will reduced by 39% and 49% respectively. Shore development will be co siderably lowered to 4.98 from 8.64. However, unlike Partridge Bre Lake, insulosity will decrease. This will occur since many islands disappear becoming additions to the mainland. Decreased flows will responsible for some increase in exchange time although not signifi



PARTRIDGE BREAST LAKE

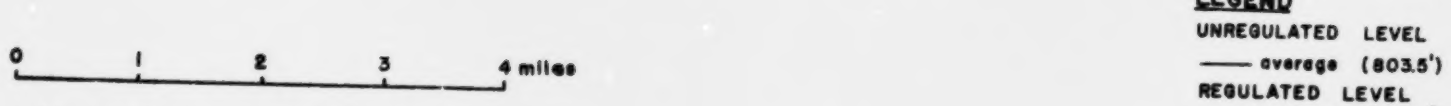

0
1
2
3
4 miles
LEGEND
UNREGULATED LEVEL
—— average (803.5')
REGULATED LEVEL
- - - - average (793.7')
minimum (788.4')

Figure 19. Drawdown map of Partridge Breast Lake.

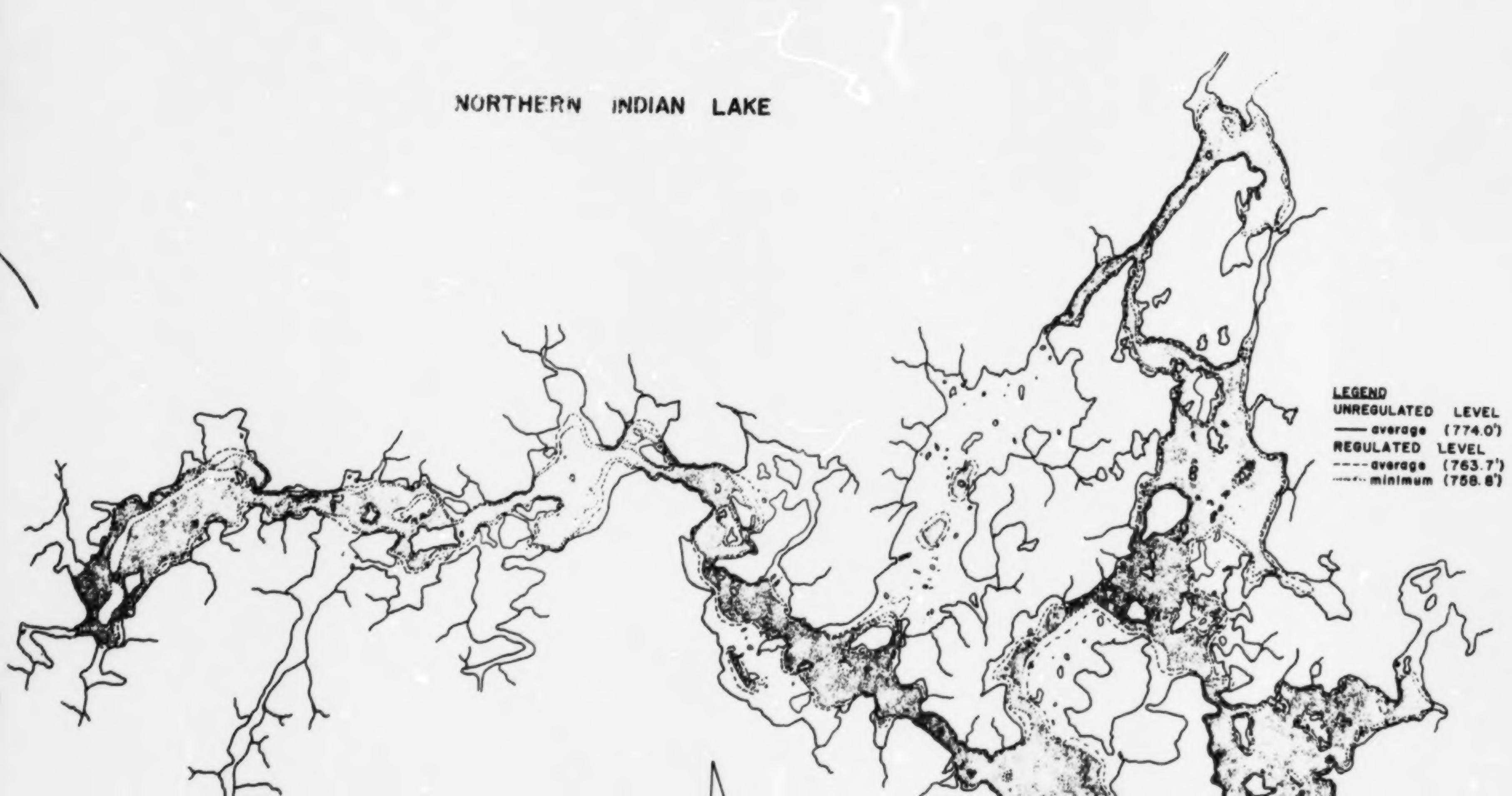

NORTHERN INDIAN LAKE
LEGEND
UNREGULATED LEVEL
—— average (774.0')
REGULATED LEVEL
- - - - average (763.7')
minimum (758.8')

Figure 20. Drawdown map of Northern Indian Lake.

The mean depth will decrease from 18.6 feet to 15.4 feet. Being larger lake, Northern Indian will not recede into the main river c as dramatically as will Partridge Breast Lake.

Fidler Lake (Fig. 21) will undergo the most dramatic chan to its unusual basin form. The large shallow basin will virtual disappear with the 8.4 foot drawdown. The water area will be re by 76% to 3.6 square miles and the volume will be reduced by 70% the major shallow portion of the lake will disappear the mean de increase by 2.3 feet. Insulosity will also increase to 7.7% wit appearance of a large island in the main river channel. Shore d ment will also be reduced to 1.26 with the lower levels. The ex time will not significantly change. However, the assumption of mixing will be more correct with the smaller area.

The new area exposed will be subject to greater yearly lev flow fluctuation after regulation than before (see Table 10). I cases the level will fluctuate during the course of a year of mor twice the amount prior to regulation. The flow fluctuation will increase by approximately 5,000 cfs. in all cases. If little fluc were to occur it would be expected that the new land exposed woul eventually invaded by emergent vegetation, sedges, mosses, and fi shrubs and trees. However, increased fluctuation in levels and f will potentially have a negative effect on the growth of shorelin vegetation and therefore, somewhat inhibit shoreline stabilizatio Normally permafrost would also invade these areas and the fluctua may prevent permafrost development somewhat.

In summary the total reduction of water area of the three a

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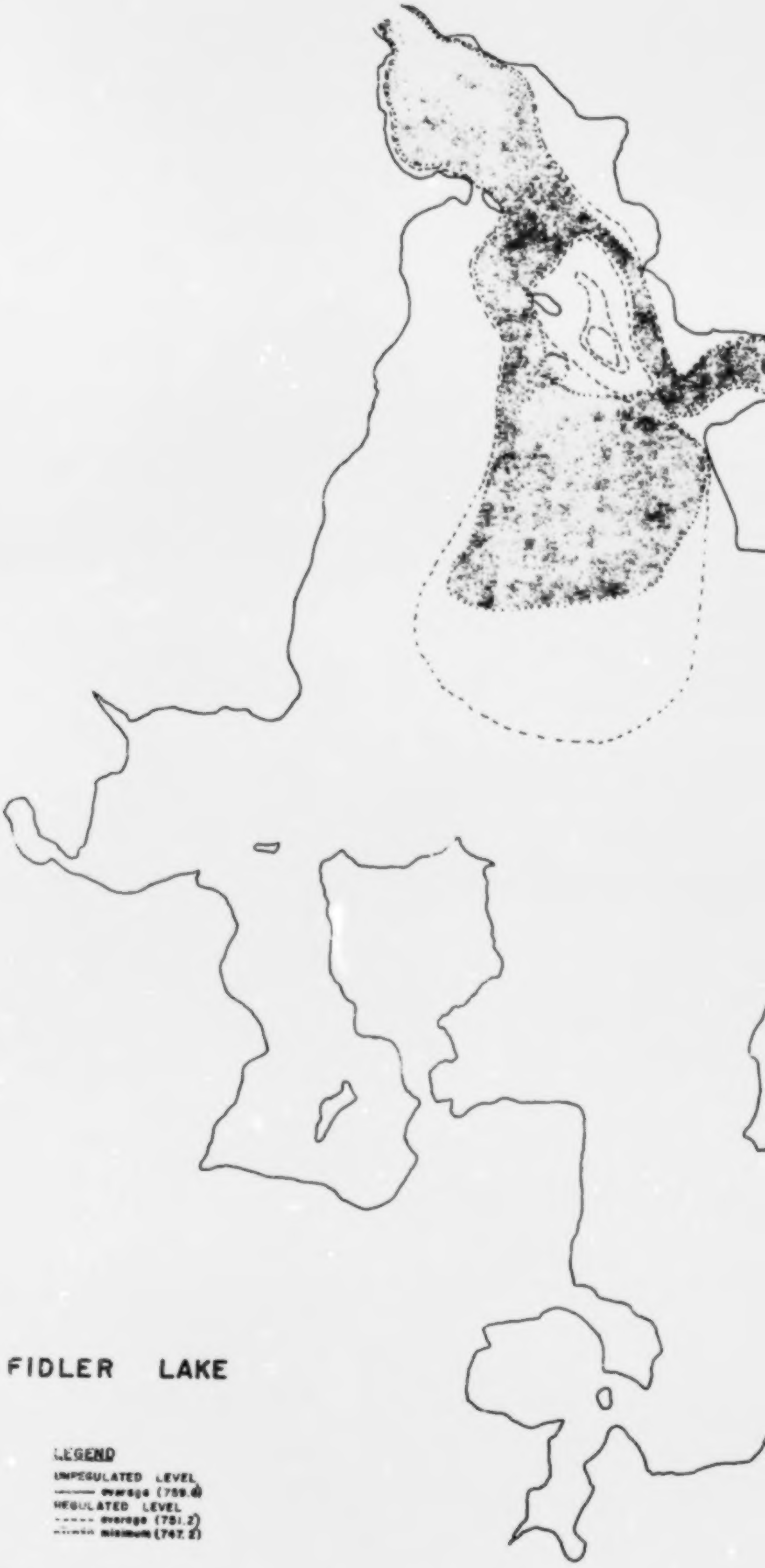
FIDLER LAKE
LEGEND
UNREGULATED LEVEL
average (759.0)
REGULATED LEVEL
average (751.2)
minimum (747.2)
0
1
2

Figure 21. Drawdown map of Fidler Lake.

Table 10. Levels and outflows for the lower Churchill River lakes before and after regulation.[1]

	Partridge Breast Lake		Northern Indian Lake		Fidler Lake	
	Before	After	Before	After	Before	After
Levels						
Average level m	245.0	242.0	236.0	232.8	232.6	229.0
(ft)	(803.5)	(793.7)	(774.0)	(763.7)	(759.6)	(751.2)
Maximum level m	245.5	243.7	236.6	234.4	232.1	230.3
(ft)	(805.1)	(799.4)	(776.1)	(768.7)	(761.3)	(755.3)
Minimum level m	244.5	240.9	235.3	231.7	231.1	228.1
(ft)	(801.9)	(790.1)	(771.8)	(760.0)	(757.9)	(748.1)
Fluctuation m	1.0	2.8	1.3	2.7	1.0	2.2
(ft)	(3.2)	(9.3)	(4.3)	(8.7)	(3.4)	(7.2)
Outflows						
Average flow cfs	35894	9043	37134	10336	37223	10434
Maximum flow cfs	43270	24795	44803	22659	44855	22190
Minimum flow cfs	28611	1572	29472	2508	29568	2591
Fluctuation cfs	14659	23223	15331	20151	15287	19599

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[1] All values used are averages which have been published by Manitoba Water Resources (1973).

will be 36.5 square miles, 56% of this loss being on Northern Indian Lake. The present littoral zone will disappear with the drawdown, as indicated in Figures 14 and 19-21. The increased fluctuations in levels and flows will have a definite negative effect on stabilization of a new littoral zone. This coupled with the reduced aquatic habitat and reduced spawning areas will have a detrimental effect on the biology of these lakes, including the commercial fishery.

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APPENDIX 5 - VOL. 2 - E

HYDROGRAPHIC SURVEY OF LAKES ON THE LOWER CHURCHILL AND RAT-BURNTWOOD RIVERS AND RESERVOIRS AND LAKES ON THE NELSON RIVER

HYDROGRAPHIC SURVEY OF
LAKES ON THE LOWER CHURCHILL
AND RAT-BURNTWOOD RIVERS AND
RESERVOIRS AND LAKES ON THE NELSON RIVER

by

T. R. CLEUGH
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
August, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

ABSTRACT

a) Lower Churchill lakes:

Chemical parameters at Opachuanau Rapids, Missi Falls, Wood Lake and the lower Churchill River lakes (Partridge Breast, Northern Indian and Fidler) were examined during 28 February - 24 September, 1973. Water analyses of the Churchill River sites (all except Wood Lake) were relatively uniform in 1973 and gave mean values for Ca, Na, Mg and K of approximately 9.2 mg/l, 2.5 mg/l, 3.4 mg/l and 1.1 mg/l respectively, (Wood Lake was 16.4 mg/l, 1.1 mg/l, 3.9 mg/l and 0.5 mg/l respectively). Cl, SO_4 and Si were 1.1 mg/l, 3.9 mg/l and 1.01 mg/l respectively, (Wood Lake was 1.1 mg/l, 3.1 mg/l and 1.3 mg/l respectively). Total CO_2 was 880 μmoles for the Churchill River sites and Wood Lake had a mean value of 1203 μmoles/l. Specific conductance was in the range 75-85 μmho/cm and Wood Lake was 108 μmho/cm, the average pH value on the Churchill River sites was 7.8, and Wood Lake was 8. Total dissolved solids were 78 mg/l (Wood Lake, 82 mg/l of TDS) and TSS were less than 10 mg/l at all sample sites throughout the sample period. NO_3-N and TDN for all samples on the Churchill River sites averaged 23 μg/l and 306 μg/l, Wood Lake samples were not analyzed. Susp N was 85 μg/l and Wood Lake was 68 μg/l. Total dissolved phosphorus and suspended phosphorus were 19 μg/l and 8 μg/l respectively, Wood Lake analysis showed 13 μg/l and 6 μg/l respectively. Loading at Northern Indian Lake was computed at 7.1 μgm $P/m^2/yr$ for 1973 and post impoundment loading is estimated at 2.9 μgm $P/m^2/yr$.

The lakes were isothermal in summer reaching a maximum temperature in August of 18.1°C. Wood Lake, during mid summer only, showed thermal stratification at the deepest part of the lake (32 meters) where a difference of 6.2°C existed between epilimnion and hypolimnion. Dissolved oxygen was near saturation, saturated or super-saturated in all the lakes throughout the sample period, except after ice-out when dissolved oxygen ranged from 31-77% saturation. The lakes were relatively untransparent in 1973 with a Secchi disc range of 1-3.5 meters.

Post impoundment and diversion water quality will be severely affected by the reduction of Churchill River water and the consequential lower lake level. Future discharge water quality will depend upon changes within Southern Indian Lake, but will likely produce water somewhat more similar to that of Wood Lake in substantially reduced lake basins. Nutrient loading from Missi Falls will be reduced 7.1 gms P/m^2 to 2.9 gm P/m^2, but this loading should be adequate to support good algal growth. Winter thermal stratification and oxygen depletion may be more substantial after diversion, but it is unlikely to have a significant negative affect on the system.

b) Rat-Burntwood Lakes:

Chemical parameters of nine diversion route lakes were examined. The chemical parameters were relatively uniform between all lakes. Water analysis in 1973 gave mean values for Ca, Na, Mg and K of 15, 2, 4.2 and 0.9 mg/l. Cl, SO_4, and Si were 1, 4, and 0.7 mg/l, total CO_2 was 1100 μmoles/l. Specific conductance was in the range 88-195 μmho/cm at 25°C and pH 7.1-8.2 units. Total dissolved solids were 76-96 mg/l and total suspended solids were less than 10 mg/l. NO_3-N was often undetectable in summer (<1 μg/l) but reached winter values of 51-96 μg/l. Suspende nitrogen and total dissolved nitrogen were in the range 107-187 and 48 600 μg/l. Total dissolved phosphorus and suspended phosphorus were <1-35 and 15-22 μg/l. Loading at Wuskwatim Rapids was computed at 2.1 gms P/m^2/year.

The lakes were isothermal in summer reaching a maximum temperat of 20°C. A pronounced thermal stratification occurred in winter in th lakes sampled. In surface waters dissolved oxygen was at or near saturation levels in all the lakes except after ice-out. Bottom water had reduced oxygen levels in the winter. The lakes were relatively un transparent in 1973 with a range of 0.5-2.5 meters.

Diversion and impoundment will alter the water quality of the n reservoir and the downstream reaches. Calcium, magnesium and dissolve inorganic carbon concentrations will be lower in the mainstem reservoi while backwater areas will be similar to the present diversion route l inflowing Churchill River, initially clearer than the present Rat Rive will have its transparency reduced because of eroding shorelines. Tur will be especially high below the reservoir where active river channel cutting will occur. Within the new reservoir oxygen depletion, potent severe in shallow isolated bays, will be more pronounced than at prese but mainstem regions should remain sufficiently oxygenated to support substantial biological communities.

c) Nelson River reservoirs:

The Nelson River is substantially more concentrated than the

Churchill River for most chemical constituents. The ranges for maj cations and anions were: sodium, 9.5-17.2 mg/l; potassium, 2.1-4.2 calcium, 22-34 mg/l; magnesium, 8.1-13.8 mg/l; chloride, 14-22 mg/l silicon, 0.17-1.7 mg/l; sulfate, 17-40 mg/l; and inorganic carbon v 1206-2645 μmoles. These values are from one (silicon) to 14 (ch times the values recorded for the Churchill River at Southern India Lake (Cleugh 1974). Dissolved nutrients exhibited ranges comparabl to those observed on the Churchill River. Transparency was signifi lower than for the Churchill system. On the mainstem Nelson River Secchi disc depth never exceeded one meter, and this is attributabl high turbidity as total suspended solids ranged from 10-30 mg/l dur the summer.

In Kettle Reservoir a station was set up in an inundated bay (Moose Creek) off the mainstem reservoir. Physical and chemical par in the bay were quite different from those in the mainstem and were large part produced by inundation. Especially noteworthy was the mu higher concentration of total dissolved phosphorus (28-101 μg/l) com pared to the Nelson mainstem (1-41 μg/l). The source of this phosph is probably inundated soils and vegetation. Secchi disc transparenc was higher than the mainstem at 1.5-2.6 m, but the water was highly colored and dark brown. A slight thermocline was present throughout the sampling period in Moose Creek. Reduced oxygen concentrations w always observed in Moose Creek ranging from 25-100% of saturation at meter to 20-63% at one meter above the bottom these values were the observed throughout the entire study area and are the result of deca organic debris. These water quality changes observed at Moose Creek probably typical of what may be expected in inundated areas of most northern reservoirs.

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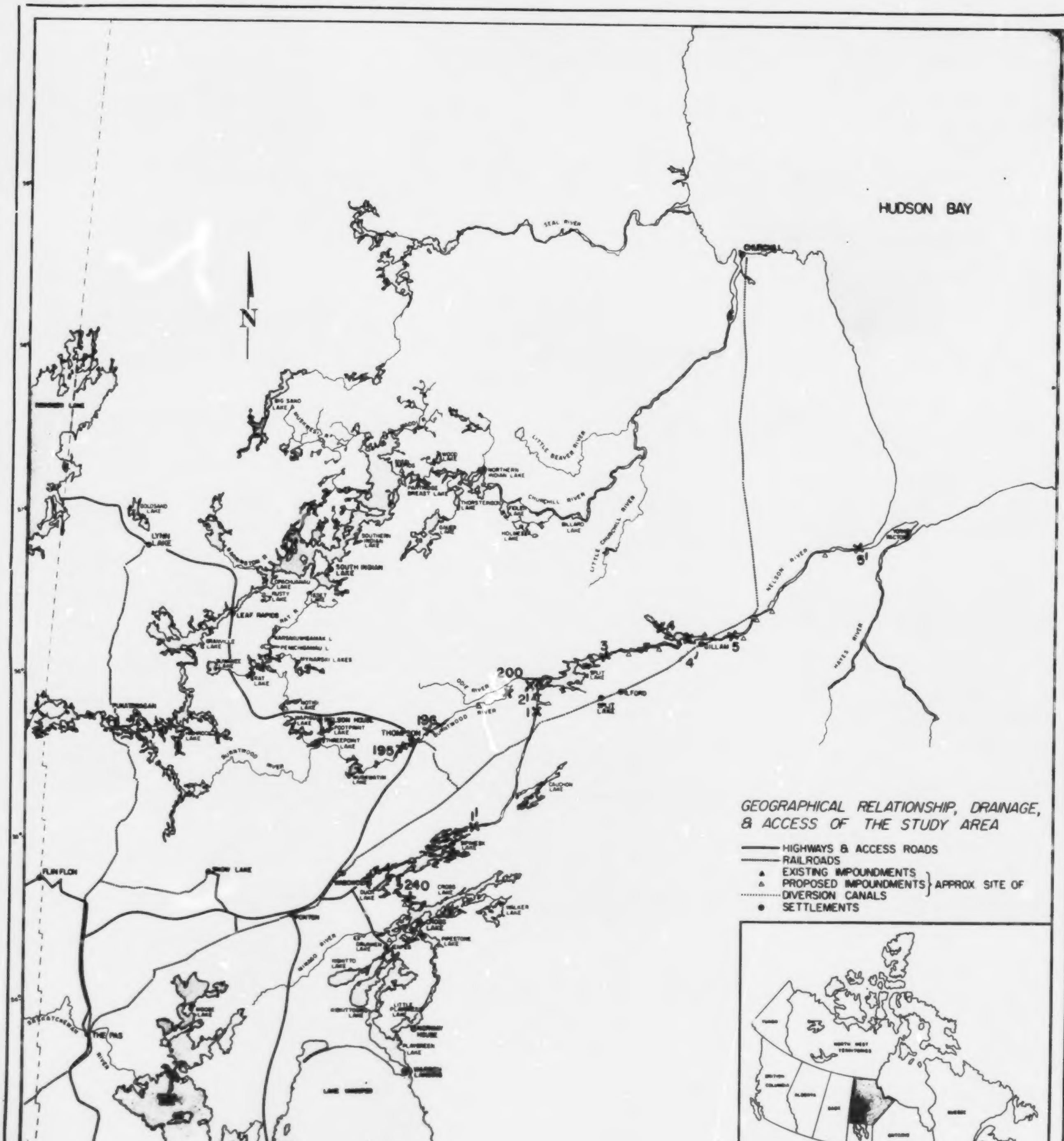
1. INTRODUCTION

The major and minor chemical constituents of natural waters are the most basic parameters influencing the quality and abundance of biological populations. Water quality is also sensitive to culturally induced disturbances such as impoundment. Recognition of this by the Fisheries-Limnology component required that it conduct a detailed hydrographic survey of the lakes to be affected by the Manitoba Hydro development of the hydroelectric potential of the Churchill and Nelson Rivers. In 1973 the lakes on the Churchill River below Southern Indian Lake, inlet and outlet to Southern Indian Lake, and Wood Lake (off the Churchill River) were monitored. The results of these analyses are discussed within section 3 of this report. Also monitored in 1972-73 were nine lakes in the Rat-Burntwood drainage which is the diversion route for the Churchill River under the Hydro proposal. The results of this survey are discussed in section 4 of this report. In addition the natural lakes and reservoirs on the Nelson River were monitored in 1972-73 to gain insight into what demonstrable affects on water quality impoundments on the Nelson had caused. These results are discussed in section Complete results of all analyses are given in the appendices at the end of the report. Figure 1.1 gives the drainage relationships of and access to the study area.


HUDSON BAY
N
SEAL RIVER
CHURCHILL
LITTLE BEAVER RIVER
CHURCHILL RIVER
NORTHERN INDIAN LAKE
SOUTHERN INDIAN LAKE
SOUTH INDIAN LAKE
LITTLE CHURCHILL RIVER
LYNN LAKE
LEAF RAPIDS
NELSON RIVER
HAYES RIVER
GILLAM
THOMPSON
BURNTWOOD RIVER
ODEI RIVER
SPLIT LAKE
ILFORD
FLIN FLON
SNOW LAKE
WABOWDEN
CROSS LAKE
THE PAS
SASKATCHEWAN RIVER
GRASS RIVER
LAKE WINNIPEG
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5'
GEOGRAPHICAL RELATIONSHIP, DRAINAGE, & ACCESS OF THE STUDY AREA
HIGHWAYS & ACCESS ROADS
RAILROADS
EXISTING IMPOUNDMENTS
PROPOSED IMPOUNDMENTS
DIVERSION CANALS
APPROX. SITE OF
SETTLEMENTS

Figure 1.1 Scale 1" - 90 mi (approx.)

Geographical relationship, drainage and access of the study area.

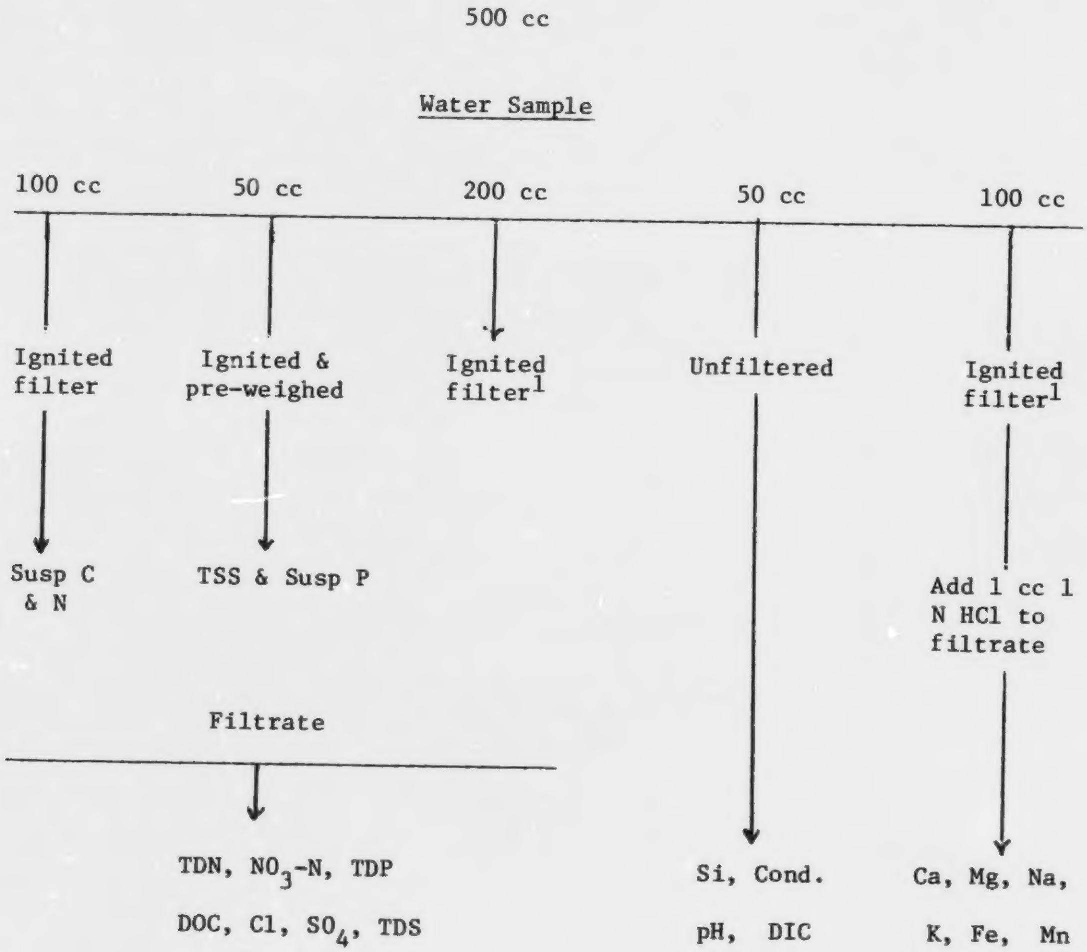
2. METHODS

Methods of water collection, field observations and chemical analyses were identical to those used on Southern Indian Lake (Cleugh 1974). Sampling was conducted from a fixed-wing aircraft and water was collected with a van Dorn sampler. Water samples (500 cc) were packed with ice and shipped in dark coolers to the Freshwater Institute, Winnipeg. Samples were generally analyzed within 48 hours of collection.

Temperature, dissolved oxygen, specific conductance and transparency determinations were done in the field. Temperature (°C) and dissolved oxygen (ppm) were measured with a YSI model 54 meter. The dissolved oxygen meter was calibrated by Winkler analyses. Specific conductance was measured with a YSI SCT meter, and transparency estimated using a 20 cm Secchi disc having alternate black and white quadrants. Chlorophyll-a was also sampled in the field filtering 200 cc of water through an ignited GF-C Whatman glass fiber filter.

Procedure for sample analysis is given in Table 2.1. Chemical species analyzed and the analyses by station are listed in the appendices All analytical methods are described in Standard Methods, 1971, and Armstrong and Schindler, 1971. Ionic balances were between 80-90% for Rat-Burntwood Lakes and 68-80% for lower Churchill lakes indicating a fairly reliable analytical procedure.

Table 2.1. Flow diagram for water sample analysis.


500 cc
Water Sample
100 cc
50 cc
200 cc
50 cc
100 cc
Ignited filter
Ignited & pre-weighed
Ignited filter1
Unfiltered
Ignited filter1
Susp C & N
TSS & Susp P
Add 1 cc 1 N HCl to filtrate
Filtrate
TDN, NO3-N, TDP
DOC, Cl, SO4, TDS
Si, Cond.
pH, DIC
Ca, Mg, Na,
K, Fe, Mn

1. Filter paper discarded
2. All filter papers are Whatman GF/C
3. Chlorophyll was filtered in the field and the filtrate discarded

3. THE LOWER CHURCHILL LAKES

3.1. Geography and flow:

The lower Churchill River lakes are located in northern Manitob on the Churchill River below Southern Indian Lake. The lakes studied this survey are Partridge Breast, Northern Indian and Fidler which are located on the Churchill River. Wood Lake, off the river on the Precambrian Shield was also studied to evaluate the significance of high discharge to the ecology of the lakes.

The water level on the lakes fluctuate, in the natural state, as the discharge from Southern Indian Lake varies. The historic mean monthly outflow at Missi varies from a minimum flow of 22,500 cfs to a maximum of 83,100 cfs with a long-term mean of 35,700 cfs. Regulated minimum conditions at Missi will be 1500 cfs in winter and 500 cfs in summer with an average of 8,900 cfs. These reduced flows will result in a wider range of water level fluctuations in the lakes (Brown 1974), and lower mean water levels, see Table 3.1, (Man. Water Resources 1973) Wood Lake has an estimated mean annual discharge of 66 cfs (Brown 1974)

3.2. Field observations:

a. Temperature and oxygen

Temperature measurements for each date are summarized in Table 3 Surface and bottom temperatures were taken on 28 February, 28 March, 14 June, 18 July, 21 August and 24 September, 1973. The Churchill River lakes were nearly isothermal throughout the sampling period, Wood Lake

Table 3.1 Historic and regulated annual lake levels for the Lower Churchill River lakes (Water Res.).

	Partridge Breast		Northern Indian		Fidler	
	Historic	Regulated	Historic	Regulated	Historic	Regulated
Minimum	800.3	788.4	769.6	757.6	756.0	746.2
Average	803.7	794.6	774.0	764.3	759.7	751.6
Maximum	812.2	810.9	784.7	783.0	769.1	767.9

Table 3.2 Summary of temperatures and dissolved oxygen Lower Churchill River lakes, 1973.

	Opachuanau Rapids	Missi Rapids	Partridge Breast Lake	Northern Indian Lake	Fidler Lake	Wood Lake
Maximum depth (meters	-	-	22.5	58	19	32
28 February 1973 - temperature °C						
0.5 meters	0	0	0	0	0	0
bottom	-	-	-	-	0	-
- oxygen, % saturation						
0.5 meters	97	98	-	-	90	-
bottom	-	-	-	-	-	-
28 March 1973 - temperature °C						
0.5 meters	0	0	-	0	-	-
bottom	-	-	-	0	-	-
- oxygen, % saturation						
0.5 meters	102	90	-	100	-	-
bottom	-	-	-	-	-	-
14 June 1973 - temperature °C						
0.5 motors	13	5	5.2	9	8	9
bottom	11	-	5	7	8	8
- oxygen, % saturation						
0.5 meters	40	41	63	40	77	44
bottom	38	-	38	50	38	31

bottom	-	-	-	14	15.1	12.5
- oxygen, % saturation						
0.5 meters	100	108	-	104	100	120
bottom	-	-	-	-	92	95

Table 3.2 cont'd

21 August 1973 - temperature °C						
0.5 meters	18.1	16.7	17.5	18	17.8	18.1
bottom	-	-	-	18	17.8	11.9
- oxygen, % saturation						
0.5 meters	120	130	130	130	130	125
bottom	-	-	-	-	110	70
24 September 1973 - temperature °C						
0.5 meters	10.9	10.2	10.2	8.1	8.8	9.5
bottom	-	-	-	8.1	8.8	9.5
- oxygen, % saturation						
0.5 meters	110	130	125	110	110	113
bottom	-	-	-	110	110	113

was isothermal after iceout and in late fall, just before ice developed stratification during the summer (18 July - 21 Augu epilimnion and hypolimnion temperatures differed by 6.2°C. M temperatures (16.7°C - 18.1°C) were recorded for all lakes on 1973. By September 24 temperatures had dropped to between 8. 10.9°C. Winter temperatures were near 0°C at all stations sa

Dissolved oxygen was determined simultaneously with te observations, see Table 3.2. Winter (February and March) oxy saturation at 0.5 m for the lakes measured, ranged from 9 At greater depths biological oxygen demand (respiration) may oxygen concentrations because, after ice-out, dissolved oxyge reduced in all lakes to a range of 40-77% for 0.5 meters and the bottom layer of water. Surface dissolved oxygen was satu super saturated for the remainder of the sampling, in all lake 21 sampling recorded super saturation in all lakes ranging fr Saturation on the bottom of all lakes ranged 70-110% for the of the sampling (18 July-24 September).

b. Transparency

Transparency was observed four times during the summer results are recorded in Table 3.3. A range of 1-3.5 m was obs Wood Lake appeared to have the greatest transparency with a ra 3-3.5 m. Churchill River lakes were most transparent immediat ice-out.

3.3. Chemical analyses:

a. Anions

The Churchill River stations appeared to be relatively

Table 3. 3 Summary of Secchi disc transparency (meters), Lower Churchill River lakes, 1973.

	Opachuanau Rapids	Missi Rapids	Partridge Breast Lake	Northern Indian Lake	Fidler Lake	Wood Lake
14 June, 1973	2	2	2	2	3	3
18 July, 1973	1	3	1.5	1.5	2	3.5
21 August, 1973	1.5	2.5	1.5	2	2	3
24 September, 1973	1.1	1.8	1.6	1.8	1.5	3

with an inorganic carbon range of 520-1300 µmoles/l for

Wood Lake had higher concentrations of CO_2 with a range

The concentration of CO_2 appeared to decrease through th

the first sampling at each station having the greatest c

CO_2 and the last sampling at each station having the low

concentration of CO_2 in the water sample. Complete anal

stations are given in appendix 3A, and ranges and means

Table 3.4 and 3.5.

Chloride and sulfate were relatively constant bet

sampled, no trends were observed. Chloride had a mean c

of 1-1.5 mg/l for all lakes. Sulfate concentration rang

mg/l (Opachuanau Rapids), 3-5.2 mg/l (Missi Falls), 3.2-

Breast Lake), 3.2-4 mg/l (Northern Indian Lake), 3.4-4.6

and 2.6-4 mg/l (Wood Lake).

Silicon had mean concentration of 0.92 mg/l (Fi

0.95-1.02 mg/l (Missi, Partridge Breast and Northern Ind

mg/l (Opachuanau Rapids) and 1.3 mg/l (Wood Lake). The

higher concentrations (1.4-1.6 mg/l) for all lakes durin

The concentrations of Si decreased to observed low conce

0.41-0.95 mg/l during the July sampling after which incr

(0.84-1.66 mg/l) were observed during the August and Sep

Wood Lake had the largest observed concentrations of sil

sampling, Opachuanau Rapids also had a large recorded co

of silicon at each sampling (mean of 1.2 mg/l). Silicon

probably reflect the activity of diatom populations.

b. Cations

Analysis of sodium on the Churchill River sample sites showed a concentration range of 2.1-3.4 mg/1, with mean value of 2.5 mg/1. Wood Lake had much lower sodium concentrations, range 1-1.2 mg/1, with a mean of 1.1 mg/1. Comparison of Opachuanau Rapids and Missi Falls demonstrates that the seasonal dilution pulse associated with spring thaw moves through Southern Indian Lake in approximately three months, July values at Opachuanau are observed at Missi in September. However, there is no observable time delay among Missi Rapids, Northern Indian Lake, and Fidler Lake indicating very rapid transport through this section of the river. Brown (1974) estimates that the exchange time for all 3 lakes is less than two weeks, and the chemical data support the short time.

Potassium (K) concentrations on the Churchill River ranged from 0.88-1.6 mg/1. The mean for all the lakes (except Wood) was 1-1.1 mg/1. Lowest observed concentrations (0.88-1 mg/1) of K were recorded during mid-summer analysis, June to July, then increased (0.98-1.23 mg/1 of K) during the August and September sampling periods. Wood Lake had a mean concentration of 0.5 mg/1 of K, with a concentration range of 0.44-0.54 for the sampling period.

Magnesium is a very interesting chemical parameter in this study as it appears to have a delayed reaction between Opachuanau Rapids and Missi Falls. The response time of the lowest recorded concentration between these two stations, July to September, may indicate a chemical pulse through the lakes, similar to that observed previously and in this report in Southern Indian Lake for silicon and sodium (Cleugh, 1974).

The recorded observations show highest concentration in the winter sampling (3.6-4.6 mg/1), the mean concentration range for all the lakes was 3.0-3.9 mg/l Mg.

Analysis of calcium (Ca) showed a relatively high concentration (mean 16.4 mg/l, range 16-17.6 mg/l) in Wood Lake, which is probably a direct result of leaching from carbonate-bearing local soil deposits. Opachuanau Rapids had the lowest observed values of Ca with a mean of 8 mg/l and a range of 6.31-9.4 mg/l. The remainder of the sampling sites have averages between 9.4-9.8 mg/l with a range in concentrations of 8.24-12 mg/l. Winter samplings recorded the highest concentrations and mid-summer (July) gave the lowest observed concentrations of calcium.

c. Specific conductivity, total dissolved solids and total suspended solids

Winter observations of specific conductance appeared to be relatively high (93-101 μmho/cm) compared to the summer sampling which was observed to be at the lowest value during the July sampling with a range of 61-73 μmho/cm. The pattern is discharge-related as the higher spring and summer discharges are derived from snow melt which dilute natural weathering products in solution. Wood Lake had the highest observed mean conductivity at 108 μmho/cm while Opachuanau Rapids had the lowest observed mean at 75 μmho/cm. The remainder of the stations had an average conductivity of 80-85 μmho/cm.

Total dissolved solids for all stations had an average concentration of 70-78 mg/l for the period sampled. No trends or peak periods were observed. Total suspended solids was always less than 10 mg/l for all stations at every sampling.

d. pH values

The hydrogen ion activity of the various lakes are reported in Appendix 3A. The lakes are neutral to slightly alkaline, with a range of 7.2-8.1 and mean values of 7.6-8. Opachuanau Rapids had a mean pH of 7.6, Wood Lake had a mean pH of 8.0 and the rest of the stations had mean pH of 7.8-7.9. The lakes, except Wood, appeared to have the same pH values on the surface and the bottom of the lakes. Wood appeared to be more acidic on the bottom during the July and August samplings, as a consequence of thermal stratification.

e. Chlorophyll-a

Chlorophyll (Chl-a) analyses in the lower Churchill study are reported in Appendix 3A, averages and ranges are given in Tables 3.4 and 3.5 Winter values for the lakes measured ranged from 0.3-1.4 μg/l with an average concentration in February and March of 0.6 μg/l. Summer (June-September) observed values ranged from 1.7-4.2 μg/l with an average of 1.8 μg/l (Opachuanau Rapids), 2.3 μg/l (Missi Falls), 2.3 μg/l (Northern Indian Lake), 2 μg/l (Fidler), and 3.1 μg/l (Wood). All the stations (except Wood Lake) have a relatively low Chl-a concentration when compared to Southern Indian Lake which had a summer mean of 4.3 μg/l (Cleugh 1973).

f. Suspended carbon and dissolved organic carbon

The analytical results for suspended carbon (Susp C) and dissolved organic carbon (DOC) are recorded in Appendix 3A, means and ranges are given in Tables 3.4 and 3.5. Susp C and DOC appear to vary inversely with each other in chemical concentration, similar to the Diversion Route survey (p. 47). When Susp C had a high value (mid-summer, 1140-1500 μmoles/l), DOC was at the corresponding low value (180-250 μmoles/l), and when Susp C was at the low winter value (280-430 μmoles/l), DOC was in high concentration (2122-2356 μmoles/l).

Suspended carbon had a concentration range during the sampling period of 280-1500 μmole/l, with averages of 608 μmole/l (Opachuanau Rapids), 784 μmole/l (Missi Falls), 679 μmole/l (Northern Indian Lake), 756 μmole/l (Fidler Lake) and 463 μmole/l (Wood Lake). The concentration of Susp C increased during the sampling to an observed peak, in all lakes, during the June analysis, the values of Susp C then decreased in the later samplings. Wood Lake had the lowest concentrations observed at any sampling time and consequently a much lower average (463 μmole/l).

Dissolved organic carbon had a concentration range, during the sampling period, of 141-2356 μmole/l, and an average value of 888 μmole/l (Northern Indian Lake) and 803 μmole/l (Fidler Lake). Recorded concentrations of DOC were relatively low in mid-summer (June) with a range of 180-260 μmoles/l, whereas they were relatively high during the winter analysis, 2122 μmole/l for Fidler Lake and 2356 μmole/l for Northern Indian Lake. Recorded analysis indicate the concentration of DOC decreased from the high value to the lowest recorded value in June and then increased during the remaining samplings.

g. Nitrogen

The study analyzed for nitrate (NO_3-N), total dissolved nitrogen (TDN) and suspended nitrogen (Susp N) during the 1973 sampling period. The analytical results are presented in Appendix 3A and the mean concentrations and ranges are recorded in Tables 3.4 and 3.5.

Nitrate analysis for the winter sampling showed a range of 41-85 μg/l for the lakes sampled in February and March. June and July values were much lower with a range of 0-10 μg/l for all the sample sites. August sample concentrations of NO_3-N occupied the very narrow range of <1-2 μg/l and September values increased to 1-9 μgm/l. Means of all analyses for Opachuanau, Missi and Northern Indian Lake were 24, 22 and 22 μg/l respectively. The variation in nitrate concentrations reflects the periodicity of algal activity.

TDN during the winter analysis for Opachuanau, Missi, Northern Indian and Fidler Lakes ranged from 323-450 μg/l. Summer values of TDN for all the lakes ranged from 158-398 μg/l, and mean concentrations of TDN were 287-325 μg/l which is within the range reported for Southern Indian Lake (Cleugh 1973) but much lower than the Diversion Route lakes (480-600 μg/l, p. 49).

Suspended nitrogen had peak values during mid-summer 1973 and in most lakes (all except Fidler) the peak was observed during the August sampling. Fidler Lake had high values, 117-159 μg/l, during June sampling. All the Churchill River sampling sites had maxima in the range of 101-197 μg/l, Wood Lake had a peak of 72 μg/l. Winter Susp N values ranged from 15-61 μg/l. For all samples means were 91 μg/l (Opachuanau), 78 μg/l (Miss), 80 μg/l (Northern Indian), 90 μg/l (Fidler), and 68 μg/l (Wood).

h. Phosphorus

Total dissolved phosphorus (TDP) was in the range of 19-69 μg/l during February and March sampling of Opachuanau, Missi, Northern Indian and Fidler sample sites. Summer analyses showed a range of 6-24 μg/l at all sample sites. No values less than 6 μg/l were observed. The values recorded for Southern Indian Lake (Cleugh 1973) are similar to the lower Churchill River lakes.

An inverse relationship between suspended and dissolved forms of phosphorus was observed similar to that for nitrogen. Suspended phosphorus (Susp P) appeared to have low concentrations of 3-5 μg/l during the winter analysis. Values increased to 8-25 μg/l on the Churchill River sampling sites and remained within this range for the rest of the sampling. Wood Lake had a low range of 4-7 μg/l of Susp P during summer analysis. Mean values of Susp P were 8 μg/l for Opachuanau, Missi and Northern Indian, 9 μg/l for Fidler and 6 μg/l for Wood.

Phosphorus loading rates were calculated for Northern Indian Lake as an indication of the level of loading to be expected in the lower Churchill Lakes. Incomplete data dictated chemical concentration extrapolation for some months. Estimated concentrations and loading for 1973 are presented in Tables 3.6 and 3.7. Loading was computed as follows:

$$\text{Loading (gm/sec)} = \frac{\text{Discharge}}{1000}\,(\text{cfs}) \times \frac{28.31}{1\ \text{cfs}} \times \frac{\text{mg (P)}}{1}$$

Annual loading is computed as follows:

$$\text{TDP, } 24.76\ \text{g/sec} \times \text{sec/yr} = 7.81 \times 10^{5}\ \text{kgm/yr}$$

$$\text{Susp P, } 7.66\ \text{g/sec} \times \text{sec/yr} = 2.41 \times 10^{5}\ \text{kgm/yr}$$

$$\text{Total P, } 32.4\ \text{g/sec} \times \text{sec/yr} = 1.022 \times 10^{6}\ \text{kgm/yr}$$

Annual areal loading of total phosphorus for Northern Indian Lake is computed as follows:

$$(\text{Area } 144.7\ \text{km}^{2},\ \bar{x}\ \text{depth} = 5.7\ \text{m}),$$

$$L = \frac{1.022 \times 10^{6}}{144.7\ \text{km}^{2}}\ \text{kg} = 7.1\ \text{g P/m}^{2}\text{/yr}$$

Table 3.4.Ranges of chemical parameters for the stations sampled in this study.

	Opachuanau Rapids	Missi Falls	Partridge Breast Lake	Northern Indian Lake	Fidler Lake	Wood Lake
CO_2 µmole/l	520-990	545-1180	558-1180	607-1301	601-1300	948-1770
Cl mg/l	1-1.5	1-1.5	1-1.5	1-1.2	1-1.4	1-1.2
SO_4 mg/l	3.4-4.8	3-5.2	3.2-5	3.2-4	3.4-4.6	2.6-4
Si mg/l	0.94-1.6	0.56-1.5	0.7-1.3	0.42-1.54	0.41-1.4	0.85-1.66
Na mg/l	2.1-3.4	2.14-3.3	2.09-2.65	2.1-3	2.09-3.05	1.02-1.12
K mg/l	0.9-1.23	0.88-1.4	1-1.04	0.88-1.2	0.88-1.57	0.44-0.54
Mg mg/l	2.32-3.9	2.84-4.6	2.79-3.28	2.97-4.62	3.01-4.43	3.9-4.19
Ca mg/l	6.31-9.4	8.26-11.1	8.31-9.43	8.24-12	8.8-10.8	16-17.6
Mn mg/l	0-0.02	0-0.03	0-0.03	0-0.03	0-0.07	0-0.03
Fe mg/l	0-0.15	0-0.19	0-0.08	0-0.06	0-0.06	0-0.07
NO_3-N µg/l	1-85	1-75	1-8	1-69	0-47	1-8
TDN µg/l	158-450	261-425	236-315	230-398	198-432	235-303
Susp N µg/l	36-143	32-124	74-197	40-102	15-159	52-81
TDP µg/l	6-25	10-35	11-69	-	11-26	8-18
Susp P µg/l	4-13	3-15	3-13	-	3-25	4-7
Chl a µg/l	0.5-3.1	0.4-4.2	-	0.5-3.4	0.3-3.8	2.3-3.7
Cond µmho/cm	63-89	61-101	73-93	74-85	80-98	97-113
pH units	7.2-8	7.6-7.9	7.6-7.9	7.8-8	7.8-8	7.8-8.1
TDS mg/l	50-107	50-125	60-123	60-85	60-96	80-83
TSS mg/l	10	10	10	10	10	10
Susp C µmoles/l	330-960	430-1230	910-1140	280-1940	290-1940	300-640
DOC µmoles/l	-	245-800	260-667	213-2356	141-2122	170-1025

Table 3.5.Mean concentrations (all analyses) of chemical parameters measured in this study.

	Opachuanau Rapids	Missi Falls	Partridge Breast Lake	Northern Indian Lake	Fidler Lake	Wood Lake
CO_2 µmole/l	638	827	819	897	908	1203
Cl mg/l	1.1	1.1	1.2	1.1	1.1	1.1
SO_4 mg/l	4	4.3	3.6	3.6	3.8	3.1
Si mg/l	1.2	0.97	0.95	1.02	0.92	1.3
Na mg/l	2.6	2.6	2.4	2.5	2.5	1.1
K mg/l	1.1	1.1	1	1.1	1.1	0.5
Mg mg/l	3	3.5	3.2	3.7	3.5	3.9
Ca mg/l	8	9.4	-	9.8	9.6	16.4
NO_3-N µg/l	24	22		22	-	-
TDN µg/l	295	318		325	287	-
Susp N µg/l	91	78		80	90	68
TDP µg/l	17	20	-	25	15	13
Susp P µg/l	8	8	-	8	9	6
Chl a µg/l	1.8	2.3	-	2.3	2	3.1
Cond µmho/cm	75	81	83	80	85	108
pH units	7.6	7.8	7.8	7.9	7.9	8
TDS mg/l	78	79	88	-	70	82
TSS mg/l	<10	<10	<10	<10	<10	<10
Susp C µmole/l	608	784	679	-	756	463
DOC µmole/l	-	-	888	-	803	-

on Figure 3.1 (after Vollenweider, 1968) indicates the lake should presently be very eutrophic. However, Figure 3.1 only applies to lakes with long retention times. The Churchill River plume, based on the response time to changing chemical concentrations, appears to move through Northern Indian in much less than a month, perhaps on the order of one or two weeks. This low retention time gives algae little time to utilize nutrients, and thus the relationship between nutrient loading and algal growth is not correctly given by Fig.3.1.

Estimates of the phosphorus loading after diversion and impoundment of the Churchill River are given in Table 3.8. Calculation of the ann loading rate is as follows (allowing concentrations to remain unchanged):

TDP 6.4 g/sec x sec/yr = 1.93×10^5 kgms

Susp P 1.9 g/sec x sec/yr = 5.99×10^4 kgms

Total P 8.05 g/sec x sec/yr = 2.54×10^5 kgms.

The annual loading of total phosphorus for Northern Indian Lake is computed as follows: (Area 87.8 km^2, $\bar{x}$ depth = 4.7 m),

$$L = \frac{2.54 \times 10^5 \text{ kg}}{87.8 \text{ km}} = 2.9 \text{ g/m}^2\text{/yr}$$

The lower discharge and loading are offset in part by the reduced area of the lake. This figure is likely too high as phosphorus retention in the northern portion of Southern Indian Lake will probably be greater after diversion. However, even if phosphorus loading is halved after diversion because of greater utilization in Southern Indian Lake, nutrients should be more than adequate to support good algal growth.

3.4. Impact:

The control structure at Missi Falls and diversion through Sou Bay on Southern Indian Lake will result in reduced flows, from a mean monthly outflow of 35692 cfs to a mean monthly outflow of 8857 cfs, a consequential reduction of lake level and surface area of the lower Churchill River lakes, Partridge Breast, Northern Indian and Fidler (Brown 1974). Nutrient loading in these downstream lakes will be redu when the Churchill River is diverted, but there will likely be adequa nutrients available to sustain reasonable algal growth. Brown (1973) indicates there will be a much greater annual fluctuation of water lev after diversion. The greater drawdown could lead to greater turbidit large areas of unstable shorelines and littoral areas will be created.

The present water quality of the lower Churchill River is simil to that of Southern Indian Lake (cf. Cleugh 1974). After diversion lo inflows will have a greater influence on the water chemistry of these lakes. Wood Lake is noticeably different in many chemical parameter (CO_2, Si, Na, K, Ca, Susp N and Cond) and lower Churchill River lakes become somewhat more like Wood Lake depending entirely upon the futur influence of the Churchill River.

The lakes will likely remain isothermal during summer as they a at present as a result of wind action. Reduced oxygen levels after ic out in the present lakes indicates that there is a considerable oxygen demand in deep waters at present. Diversion could aggravate this cond Reduced winter flows may allow a more stable thermal stratification wh

Table 3.6. Estimated mean monthly values of phosphorus concentration and flow for Northern Indian Lake, 1973.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Mean monthly flow cfs	32164	29666	27906	27610	31037	38961	44143	44132	41861	38948	37105	34771
TDP μg/l	20	23	69	45	30	20	13	12	12	14	16	20
Susp P μg/l	4	3	4	6	8	10	11	11	12	10	7	5

Table 3.7. Estimated phosphorus loading, Northern Indian Lake, 1973

	Winter (Oct-Apr) $\bar{x}$ D = 32595		Summer (May-Sept) $\bar{x}$ D = 40026		Annual $\bar{x}$ D = 35692	
	$\bar{x}$ conc	Loading gm/sec	$\bar{x}$ conc	Loading gm/sec	$\bar{x}$ conc	Loading gm/sec
TDP	29.57	27.29	17.4	19.7	24.5	24.76
Susp P	5.57	5.14	10.4	11.78	7.58	7.66
Total P	35.14	32.43	27.8	32.6	32.08	32.4

Table 3.8. Estimated phosphorus loading, Northern Indian Lake, after regulation.

	Winter (Oct-Apr) $\bar{x}$ D - 4073		Summer (May-Sept) $\bar{x}$ D = 15555		Annual $\bar{x}$ D = 8857	
	$\bar{x}$ conc*	Loading gm/sec	$\bar{x}$ conc	Loading gm/sec	$\bar{x}$ conc	Loading gm/sec
TDP	29.57	3.41	17.4	7.66	24.5	6.14
Susp P	5.57	0.64	10.4	4.58	7.58	1.90
Total P	35.14	4.05	27.8	12.25	32.08	8.05

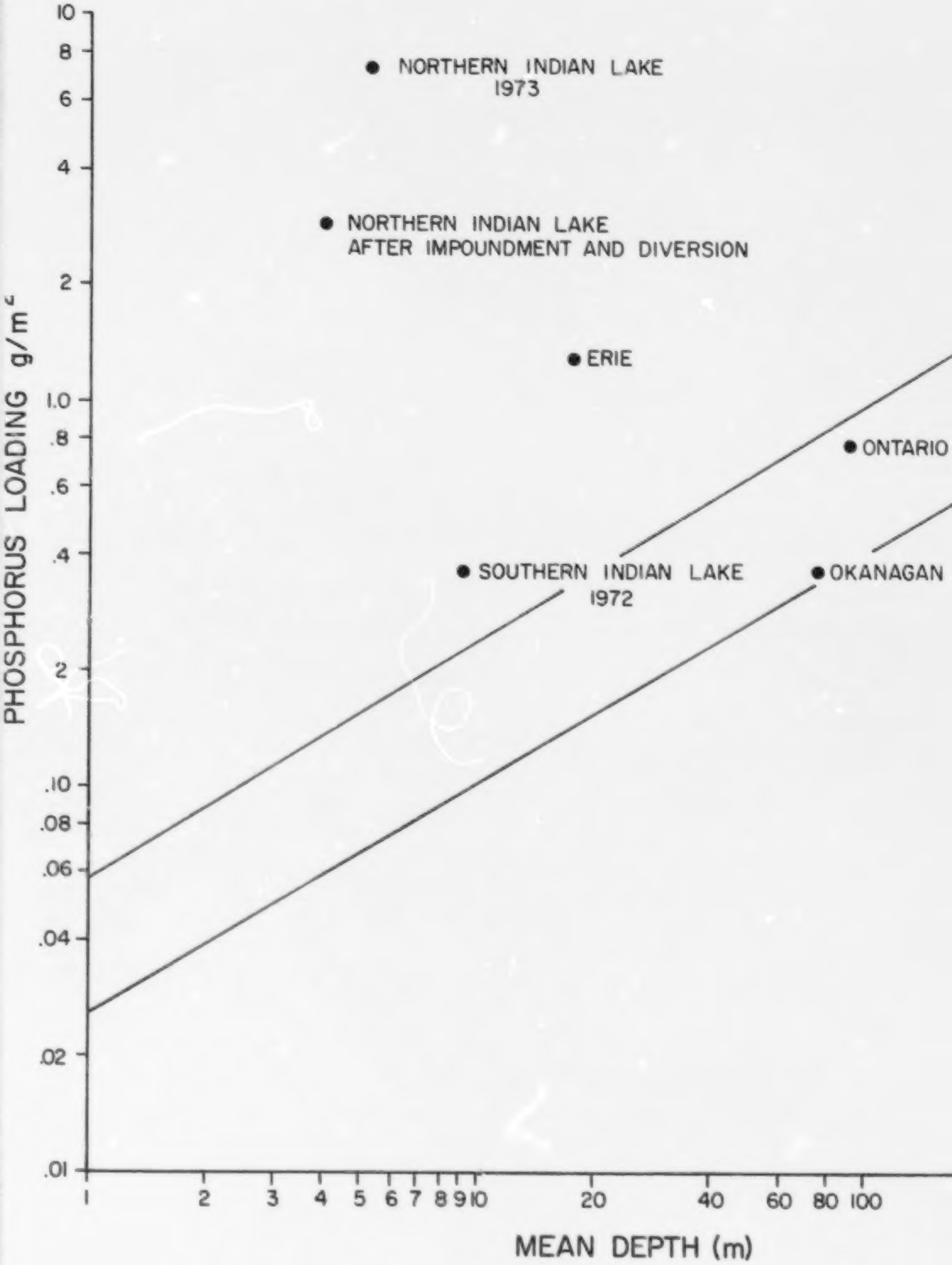


Fig. 3.1. Annual total phosphorus loading of Northern Ind
compared to other North American lakes.

could allow very low oxygen levels to occur in deeper waters as is observed in Diversion Route lakes under natural conditions. Consequently low dissolved oxygen levels may occur throughout the water column, as in the Diversion Route lakes, immediately after ice-out when deep waters and surface waters are mixed by wind action.

3.5 Summary:

1. The historical mean monthly flows of 40,026 (summer), 32,596 (winter) and 35,692 (annual) will be reduced to a regulated outflow at Missi Falls of 15,555 (summer), 4,078 (winter) and 8,857 (annual), reducing mean annual discharge by 75%.

2. The sample sites of this study were isothermal throughout the sampling periods, except for Wood Lake which had some stratification in mid-summer. Reduced flow after diversion may result in a stable winter thermal stratification in these lakes. Summer conditions will be isothermal due to wind action.

3. Dissolved oxygen levels recorded in this study were 90-102% of saturation at 0.5 meters and 31-50% near the bottom at ice-out, and saturated or super saturated for the remainder of the sample period. Diversion may reduce dissolved oxygen levels in winter due to an 87.5% reduction in water discharge (flow). Some oxygen deficiency may occur in shallow areas and in isolated bays, and low oxygen levels will occur throughout the lakes at ice-out. If winter stratification occurs, very low oxygen levels could occur in the hypolimnion. Wind action

and relatively higher flows will maintain high dissolved oxygen levels in the summer.

4. The lower Churchill River lakes are relatively untransparent with a Secchi range of 1-3 meters. Wood Lake had a Secchi range of 3-3.5 meters.

5. The influence on water quality of the Churchill River is evident in the relative uniformity of chemical parameters on the lower Churchill River lakes. The Churchill River sample sites usually occupied a very narrow range between stations and a noticeable difference from Wood Lake. The water quality of Wood Lake was influenced by local soil leaching and rain, and not by the Churchill River which produced significant differences in the concentrations of CO_2, Si, Na, K, Ca, Susp N and Cond.

6. The influence of the Churchill River can best be demonstrated by its effect on nutrient loading. The 1973 analyses showed an annual loading rate of 7.1 gms P/m^2. With impoundment and diversion of 75% (annual) of the Churchill River the loading rate will be less than 2.9 gms P/m^2, or a reduction of 41% of nutrient loading from Missi Falls discharge into the lower Churchill River lakes. Changing water quality in the northern portion of Southern Indian Lake will lead to lower concentrations of phosphorus in the Missi Falls discharge further reducing loading, but nutrients will likely remain adequate to support a similar level of algal growth.

4. THE RAT-BURNTWOOD LAKES

4.1. Geography, soils and flow:

The diversion route lakes are located in northern Manitoba, on the Rat and Burntwood Rivers system (Fig. 1.1). The Rat River rises near Southern Indian Lake and flows approximately 100 miles through six major lakes, Issett, Karsakuwigamak, Pemichigamau, Rat, Notigi, and Wapisu Lakes. At Threepoint Lake, which is immediately southeast of Wapisu Lake, the Rat River is joined by the Footprint and Burntwood Rivers. The Burntwood River flows a further 120 miles from Threepoint Lake through Wuskwatim Lake, past the city of Thompson and eventually joins the Nelson River at Split Lake. The impoundment will be located at Notigi Lake which is situated approximately at 99 20'W by 55 50'N.

The Rat and Burntwood basins are situated on the Precambrian Shield, but thick sections of glacio-lacustrine clay occur over the basin. The annual mean monthly flow at Wuskwatim Rapids is 3121 cfs, the annual minimum monthly flow is 242 cfs and the maximum is 15,746 cfs. (Man. Water Res. 1973). The averages by month for the period 1928-1966 with the minimum and maximum ranges are presented in Table 4.1. After impoundment and diversion of the Churchill River the average flow will be 31,170 cfs, with a minimum and maximum 7,718 cfs and 34,000 cfs. The mean monthly flows for the new regime are presented in Table 4.2, (Man. Water Res. 1973).

Table 4.1 Historic mean monthly flow (cfs) data at Wuskwatim Rapids, 1928-1966.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Minimum	293	260	242	264	1967	1578	493	920	360	482	545	425	242
Mean	1080	914	800	894	5933	7715	5991	4012	3626	2801	2172	1514	3121
Maximum	2202	1935	1778	2563	10733	15746	11776	11309	9654	6875	4438	2730	15746

Table 4.2 Mean monthly flows (cfs) after impoundment and diversion.

	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Minimum	17042	7990	17767	7718	10841	31041	34000	32736	24683	25060	19876	17781	7718
Mean	29457	28295	27429	26519	32120	33991	34000	33937	33384	32562	32056	30286	31170
Maximum	32461	32405	32119	32258	34000	34000	34000	34000	34000	34000	34000	33145	34000

4.2. Field Observations:

a. Temperature

Detailed temperature profiles from each sampling are shown in Figures 4.1 to 4.4 and are summarized in Table 4.3. Temperature-depth profiles were taken at least four times (14 June, 18 July, 20 August, 24 September) during 1973, four of the lakes had an additional temperature gradient taken on 28 March 1973. All the lakes were isothermal by 18 July 1973 and remained isothermal to the last sampling, 24 September 1974. The peak temperature observed for all lakes was on 20 August 1973. Four lakes, Mynarski, Notigi, Wapisu and Wuskwatim had a maximum temperature of 20°C; Karsakuwigamak had the lowest observed maximum temperature at 16.5°C, maximum observed temperatures for Issett Lake were 18.1°C, Pemichigamau Lake, 18.2°C, and Rat Lake 19.5°C. The temperatures on September 24, in all lakes, were approximately half that observed on 20 August. The lakes had temperatures of 8.7°C to 10.2°C. The most noticeable features of the thermal condition of these lakes is the rapid heating and cooling, and the isothermal condition in the summer. These lakes are shallow , exposed to wind action, and interconnected by turbulent river stretches. These features allow water temperatures to closely follow atmospheric temperatures in summer. The temperature observations on 28 March 1973 show approximately a 3°C stratification in all lakes sampled. This stratification is probably a result of reduced circulation because the ice cover prevents mixing by wind action.

b. Oxygen

Dissolved oxygen was determined simultaneously with temperature

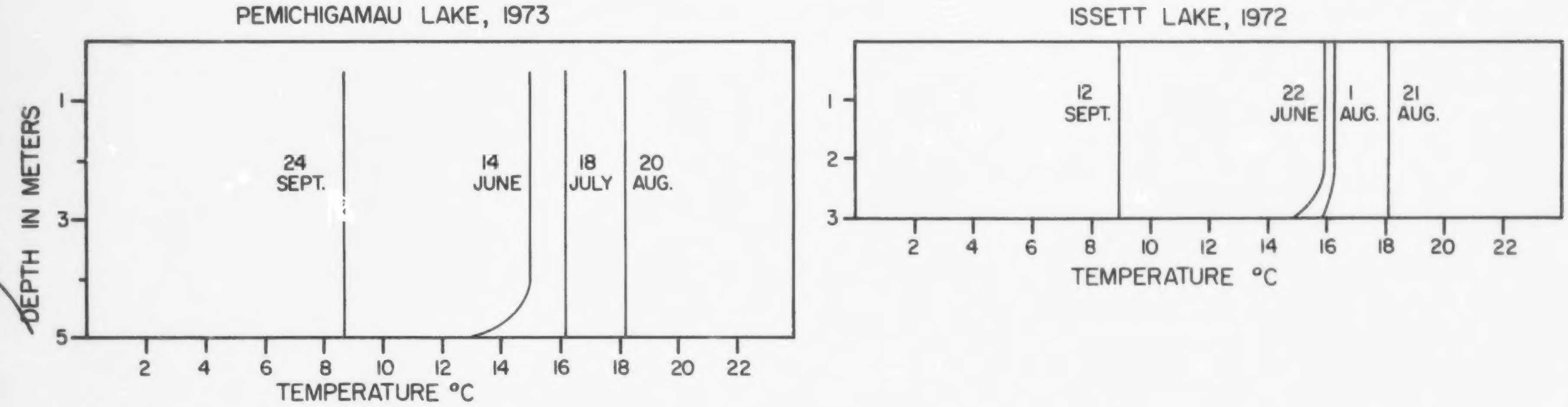


Figure 4.1 Temperature profiles on Pemichigamau and Issett Lakes, 1973

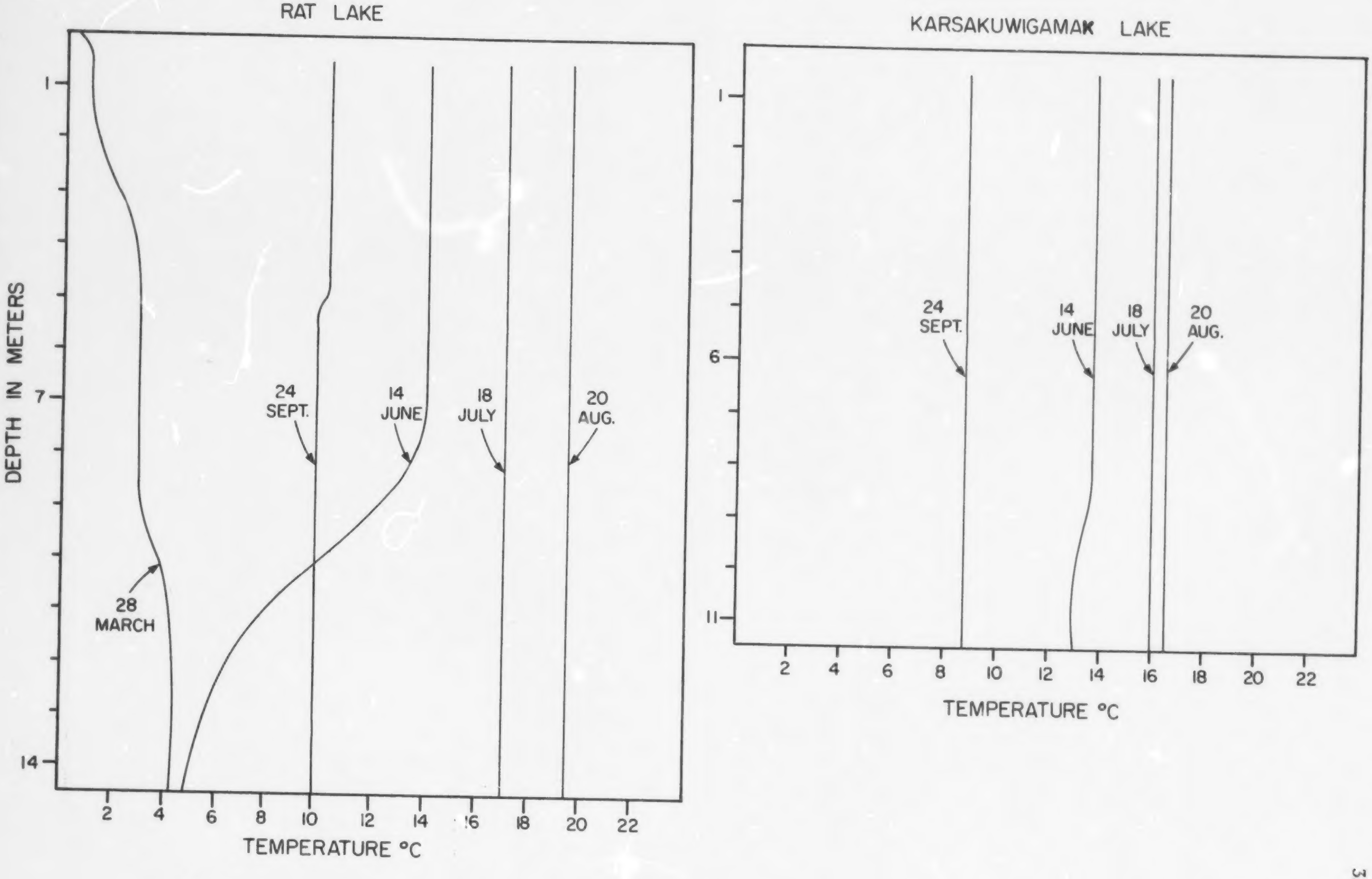
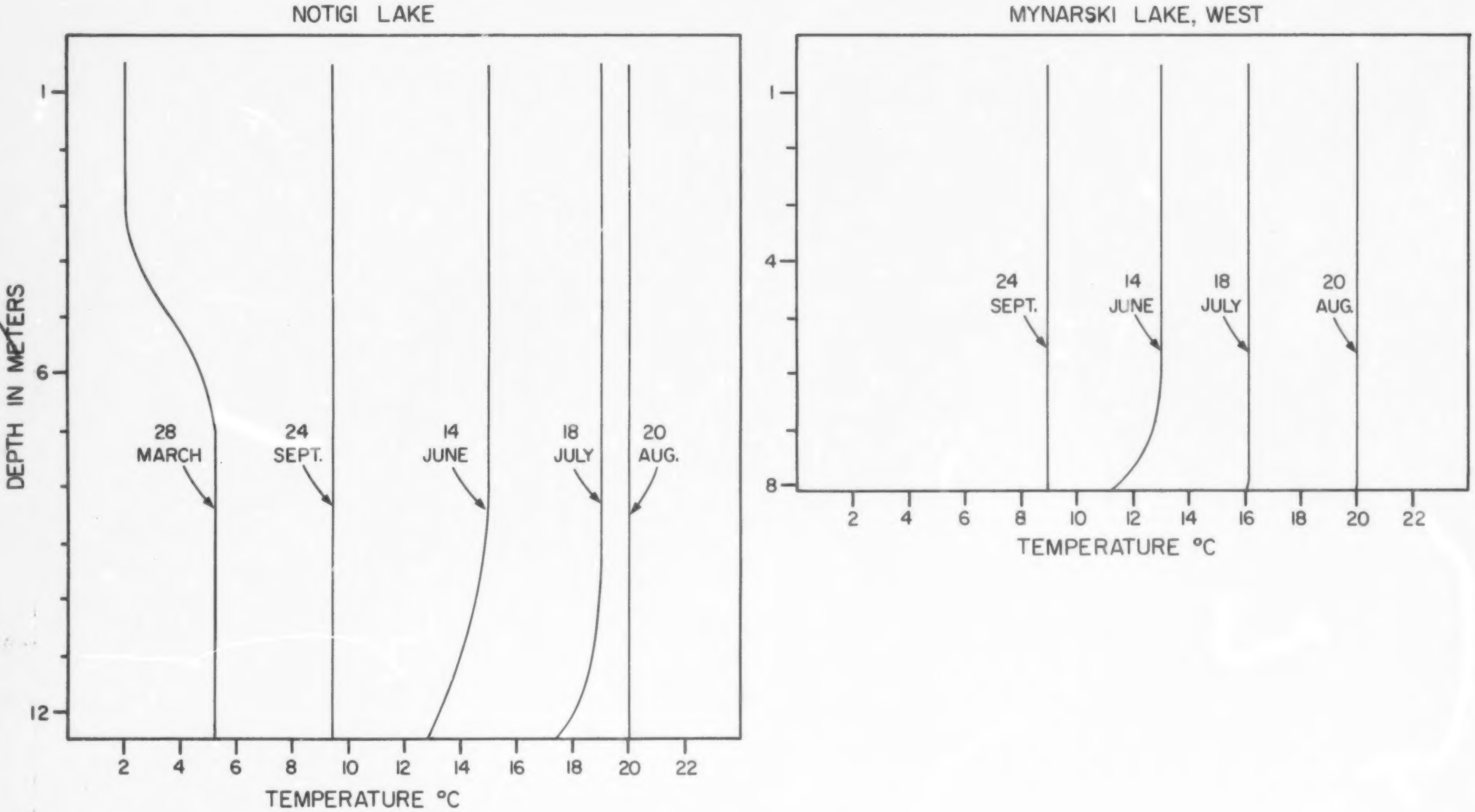


Figure 4.3. Temperature profiles of Rat and Karsakuwi


NOTIGI LAKE
DEPTH IN METERS
1
6
12
28 MARCH
24 SEPT.
14 JUNE
18 JULY
20 AUG.
2
4
6
8
10
12
14
16
18
20
22
TEMPERATURE °C
MYNARSKI LAKE, WEST
1
4
8
24 SEPT.
14 JUNE
18 JULY
20 AUG.
2
4
6
8
10
12
14
16
18
20
22
TEMPERATURE °C

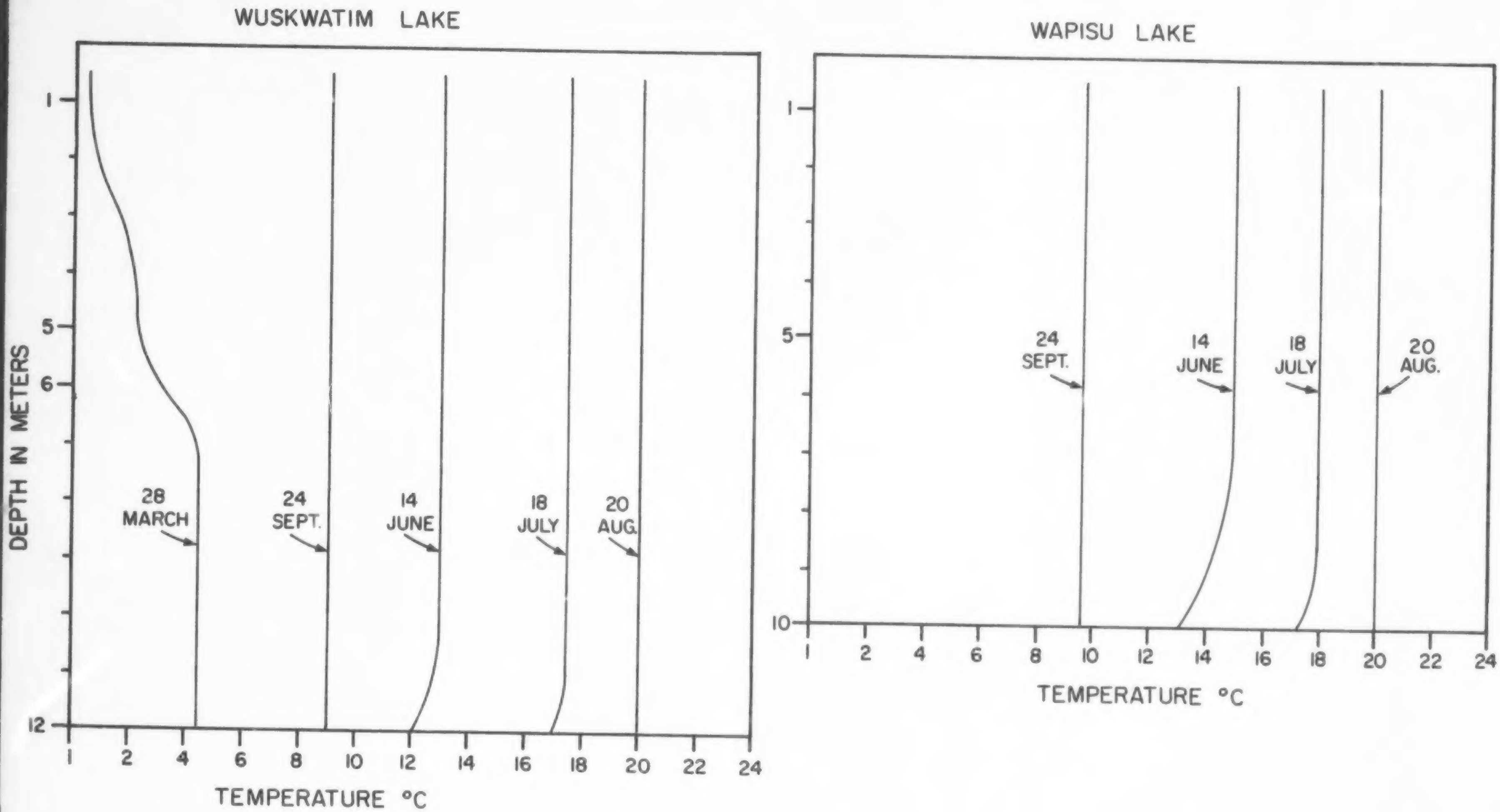


Figure 4.4. Temperature profiles of Wapisu and Wuskwatim Lakes, 1973.

observations. Oxygen concentrations were taken at 0.5 meters depth a 1 meter above the bottom of the lake, and reported in Table 4.3 as percent saturation.

Surface concentrations (0.5 m) on 28 March 1973 for the four la measured, ranged from 75-98% O_2 saturation and the bottom concentrati (B + 1 m) ranged from 32-74% saturation. Rat Lake had the lowest O_2 saturation at the bottom, 32%, Notigi and Wuskwatim had O_2 saturation of 74 and 65%.

All the lakes measured had very low oxygen saturation levels du 14 June sampling, which is immediately after ice-out when surface and bottom waters were mixed by wind action. Surface oxygen saturation levels ranged from 23-67% and bottom oxygen saturation levels ranged from 5-44%. Wuskwatim Lake had the highest saturation (67% and 44%) f both the surface and the bottom. The remaining lakes all had O_2 satur levels at the surface ranging from 23-41% and lower bottom saturation levels at 5-23%. The bottom of Rat, Notigi, Mynarski and Wapisu Lakes had very low O_2 saturation levels of 5, 7, 10 and 15% respectively on June 14, 1973.

During the remainder of the sampling period, 18 July to 24 Augus all the lakes had supersaturated oxygen concentrations. The oxygen le reached a high of 137% supersaturation in Pemichigamau Lake on 20 Augu 1973. The high degree of supersaturation during summer is probably related to high algal productivity in the lakes. Dense blue-green alga surficial blooms were present at the end of August (Hecky and Harper 1

c. Transparency

The light transparency in each lake measured was observed four

Table 4.3. Summary of temperature and dissolved oxygen of nine Rat-Burntwood lakes, 1973.

	Issett*	Karsakuwig-amak	Pemichigamau	Rat	Mynarski	Notigi	Wapisu	Threepoint	Wuskwatim
Maximum depth in meters	3	11.5	5	14.5	8.1	12.5	10	7	12
Mean depth in meters	1.75	2.01	2.15	3.72	1.68	5.30	8.03	0.72	6.24
28 March - Temperature °C, 0.5 meters	-	-	-	0.5	-	2.0	-	0	0.6
- , bottom	-	-	-	4.25	-	5.2	-	-	4.5
- Oxygen % saturation, 0.5 m	-	-	-	77	-	77	-	75	98
bottom	-	-	-	32	-	74	-	-	65
14 June - Temperature °C, 0.5 meters	16	13.8	15	14	15	15	15	-	13
bottom	15	13	13	5	13	13	13	-	12
- Oxygen % saturation, 0.5 meters	-	27	41	40	31	23	36	-	67
bottom	-	23	22	5	10	7	15	-	44
18 July - Temperature °C, 0.5 meters	16	16	16.2	17.2	16.2	18.9	18	18	17.5
bottom	15.8	16	16.2	17.1	16	17.5	17.2	-	17.5
- Oxygen % saturation 0.5 meters	-	103	105	114	110	132	123	118	116
bottom	-	103	-	104	104	131	110	-	109
20 August - Temperature °C, 0.5 meters	18.1	16.5	18.2	19.5	20	20	20	-	20
bottom	18.1	16.5	18.2	19.5	19.5	-	-	-	20
- Oxygen % saturation, 0.5 meters	-	120	137	134	130	128	128	-	126
bottom	-	-	-	123	126	-	-	-	126
24 September - Temperature °C, 0.5 meters	8.9	8.7	8.7	10.2	9	9.6	9.5	-	9
bottom	8.9	8.7	8.7	9.8	9	9.5	9.3	-	9
- Oxygen % saturation, 0.5 meters	-	116	113	106	107	100	101	-	105
bottom	-	-	-	-	-	-	-	-	-

* sampled in 1972

Table 4.4 Summary of Secchi depths, in meters, of eight diversi
lakes, 1973.

	Karsakuwigamak	Pemichigamau	Rat	Notigi	Wapisu	Three Point
June 14	1.3	1.3	1.3	1.0	1.5	-
July 18	1.3	0.8	1.3	1.3	1.5	0.5
August 20	0.6	0.6	1.0	0.5	1.2	-
September 24	1.0	1.0	1.5	1.0	1.5	-
mean	1.05	.93	1.28	.95	1.43	0.5

times during the summer of 1973, and recorded on Table 4.4. M
Lake, which drains into Rat Lake, had the greatest transparenc
through the summer of 1973. Wapisu Lake had the greatest tran
(1.43 m) of those lakes on the Rat River; Wuskwatim was the le
transparent (0.5 m) but this lake is also affected by two othe
Burntwood and Footprint, which likely have an influence on the
parency. The greatest transparency, in all the lakes measured
observed after ice-out, 14 June 1973, and tended to decrease t
the summer. The lowest observed Secchi depths for all the lak
20 August 1973. Although located on the Shield, comparison
values of Table 4.4 with Table 4.9 which gives Secchi disc val
more typical Shield lakes, indicates one way in which the Dive
lakes are significantly different. The lowest Secchi disc dep
Table 4.9 (3.7 m) is more than two times greater than the high
in Table 4.4 for a Rat River lake. The poor transparency in t
is attributable to high turbidity caused by weathering of clay
in the river basin.

4.3. Chemical analyses:

a. Anions

Chloride, sulfate and inorganic carbon (Tables 4.5, 4.6,
were relatively uniform in distribution among all the diversion
lakes. Chloride mean concentrations of 1-1.3 mg/l, sulfur mean
trations of 3.8-4.2 mg/l and carbon dioxide mean concentrations
1250 μmoles/l were observed during the 1973 sampling period. C
analyses are given in Appendix 4A.

Silicon had an average concentration range in all the div

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route
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route lakes, except Issett and Mynarski, of 1.2-1.6 mg/l.
Mynarski Lakes had a low mean concentration of 0.7 mg/l. R
and Wuskwatim Lakes were also analyzed on 28 March 1973, se
and the analyses showed a higher concentration of silicon,
and 2.03 mg/l respectively. This may indicate silicon rete
these lakes during the summer months because of diatom prod

Tables 4.8 and 4.9 present summaries of the water che
Churchill River lakes and Shield lakes for comparison with
Route lakes. The most notable difference among the anions
Although analytical methods vary, total CO_2 in the Diversio
is at least double that in any of the Shield lakes in Table
Weathering of carbonate-bearing glaciolacustrine clays is p
responsible.

In Table 4.7 summer and winter concentrations of chem
for three diversion route lakes and station 20 on Southern
After diversion, water from station 20 will dominate the re
can be expected that the aquatic chemistry of the mainstem
the reservoir will be similar to station 20 while isolated
Churchill plume will be similar to the present lakes. This
distribution of water masses is clearly evident in the pres
Indian Lake. The most substantial change in anions will in
carbon which will be reduced in the mainstem lakes.

b. Cations

Analysis of major cations revealed no discernible dif
among the diversion route lakes during the 14 June - 24 Sep
sampling. The values reported occupied a narrow range for
measured. The mean concentrations for the lakes ranged fro

Table 4.5 Comparison of the mean concentrations of the measured chemical parameters on the Diversion Route lakes, 14 June - 24 September, 1973. (Issett Lake was sampled in 1972)

	Total CO_2	Cl	SO_4	Si	Na	K	Mg	Ca	Mn	Fe	NO_3-N	TDN	Susp N	TDP	Susp P	Chl a	Cond	pH	TDS	TSS	Susp C	DOC
Issett	-	1	4.2	0.65	-	-	-	14	0.03	0.2	-	-	-	12	-	3	90	8	80	10	970	-
Karaskuwigamak	1250	1.1	4	1.2	1.9	0.86	4.1	15	0.01	0.12	3	600	107	19	14	3	117	7.7	90	5	730	1300
Pemichigamau	1022	1	3.9	1.3	1.8	0.93	3.9	14	-	0.13	1.7	520	144	14	15	4.8	122	7.8	96	7	920	860
Rat	1100	1.3	3.9	1.6	1.9	0.94	4.15	16	0.01	0.08	1.8	540	125	19	16	3.6	130	7.8	93	5	890	970
Notigi	1130	1.1	3.8	1.6	2.04	0.96	4.33	16	0.01	0.06	2.5	583	161	10	17	5.4	125	7.9	95	6	1030	980
Wapisu	1100	1.1	3.9	1.6	2.0	0.94	4.34	16.2	0.02	0.05	2	540	187	14	21	5.6	125	7.9	85	5	1020	1020
Threepoint*	1110	1.2	4.2	1.3	2.23	0.92	4.61	17.0	0	0.03	4	814	172	20	15	6.2	142	8.0	65	9	1140	1055
Wuskwatim	1120	1.1	4.1	1.4	2.12	0.99	4.47	16.2	0.01	0.18	1	480	150	14	18.5	4.5	120	7.9	90	9	900	1100
Mynarski	990	1	3.7	.7	1.93	.90	3.8	14.3	-	0.06	2.3	527	265	12	22	7.3	120	7.9	76	6	1640	990

* only one sample

Table 4.6. Ranges of chemical parameters on the Diversion Route lakes, 1973

	Karsakuwigamak	Pemichigamau	Rat	Notigi	Wapisu	Wuskwatim	Mynarski
CO_2	830 - 1970	850 - 1010	930 - 2057	989 - 1373	972 - 1155	990 - 1355	905 - 1060
Cl	1 - 1,2	.8 - 1.2	1 - 1.8	0.8 - 1.2	0.8 - 1.4	0.8 - 1.2	0.6 - 1.2
SO_4	3.6 - 4.4	3.4 - 4	3.4 - 6	3.6 - 6	3.6 - 4.2	3.8 - 6	3.4 - 4
Si	.92- 1.63	1.24- 1.42	1.36 - 3.62	1.23- 2.12	1.37- 1.92	1.15- 2.43	.4 - .96
Na	1.52- 2.45	1.47- 2.17	1.66 - 3.04	1.93- 2.61	1.98- 2.17	1.82- 2.66	1.82- 2.07
K	.78- .94	.78- 1.01	0.84 - 1.49	0.9 - 1.09	.88- .99	.93- 1.21	.82- .96
Mg	3.27- 4.71	3.24- 4.15	3.79 - 9.28	4.21- 6.96	3.93- 4.55	3.83- 6.93	3.47- 4.08
Ca	11.7 -17.1	11.3 -16.1	15.4 -27.9	15.4 -20.2	13.9 -17.4	13 -18.4	12.6 -15.9
Mn	0 - .02	0 - .03	0 - .04	0 - .03	0 - .07	0 - .04	0 - .03
Fe	.13- .21	.07- .17	.04 - .14	0 - .08	0 - .12	.14- .26	0 - .09
NO_3	1 - 5	1 - 3	1 -51	1 -96	1 - 7	1 -61	1 - 4
TDN	286 - 1159	222 - 1048	278 - 984	257 - 959	263 - 874	239 - 856	247 - 1161
Susp N	42 - 164	64 - 231	42 - 235	8 - 365	42 - 280	27 - 239	53 - 43
TDP	16 - 23	11 - 20	11 - 24	1 - 67	1 - 20	1 - 41	1 - 17
Susp P	9 - 17	9 - 23	3 - 27	4 - 29	10 - 27	8 - 22	8 - 34
Chl a	1.9 - 3.6	1.6 - 8.8	0.3 - 6.6	0.1 - 8.6	3.3 -12.1	0.4 - 7.1	1.1 -11.6
Cond	88 - 148	88 - 173	99 - 195	101 - 150	102 - 150	98 - 146	95 - 164
pH	7.5 - 8	7.6 - 8	7.2 - 8	7.1 - 8.2	7.85- 8	7.4 - 8.2	7.8 - 8.1
TDS	48 - 120	70 - 112	31 - 130	45 - 127	80 - 100	69 - 128	62 - 80
TSS	2 - 9	4 - 9	1 -10	1 -11	3 -10	4 - 10	2 - 9
Susp C	460 - 1010	520 - 1400	389 - 1410	343 - 1940	490 - 1230	386 - 1160	580 - 2510
DOC	1025 - 1600	502 - 1875	680 - 1354	852 - 1509	905 - 1125	980 - 1454	725 - 1300

Table 4.7. Comparison of summer and winter mean concentrations of the measured chemical parameters on 3 lakes in the Diversion Route, 1973. and station 20 on Southern Indian Lake.

	Total CO_2	Cl	SO_4	Si	Na	K	Mg	Ca	Mn	Fe	NO_3-N	TDN	Susp N	TDP	susp P	Chl a	Cond	pH	TDS	TSS	Susp C	DOC
Rat Lake																						
summer	1100	1.3	3.9	1.6	1.9	0.94	4.15	16	0.01	0.08	1.8	540	125	19	16	3.6	130	7.8	93	5	890	970
winter	1624	1	6	2.7	2.76	1.37	8.1	23	0.04	0.07	51	416	-	23	4	0.7	170	7.4	38	1	440	1300
Notigi Lake																						
summer	1130	1.1	3.8	1.6	2.04	0.94	4.33	16	0.01	0.06	2.5	583	161	10	17	5.4	125	7.9	95	6	1030	980
winter	1330	1	5	1.97	2.53	1.09	6.85	19.3	0.03	0.05	77	391	18	35	5	0.4	140	7.4	67	1	550	1450
Wuskwatim Lake																						
summer	1120	1.1	4.1	1.4	2.12	0.99	4.47	16.2	0.01	0.18	1	480	150	14	18.5	4.5	120	7.9	90	9	900	1100
winter	1222	1	6	2.03	2.6	1.2	6.92	18.3	0.04	0.17	61	450	43	31	11	2.2	135	7.4	124	4	580	1370
Southern Indian St. 20																						
summer	558	1.0	4.0	0.82	2.3	1.0	3.3	7.9	.02	.08	9.5	280	79	9.3	10	4.9	74	7.8	59	<10	652	-
winter	890	1	5	1.6	2.8	1.2	4.2	10.0	.01	.08	75	419	61	35	4	0.4	95	7.8	86	<10	-	-

Table 4.8. Comparison of some Churchill River Lakes.

	Frobisher[1]	Churchill[1]	Trout[1]	Southern Indian Lake (station 20)[3]
pH surface	8.1	8.1	7.9	
bottom	7.6	7.5	6.9	
Cl ppm	3.7	3.5	NIL	1.0
SO_4 ppm	4.4	5.8	NIL	4.0
Si ppm	4.5	2.8	0.8	1.03
Na ppm	1.4	2.3	<5	2.6
K ppm	-	-	<5	1.1
Mg ppm	8.0	10.8	6	3.6
Ca ppm	14.6	25.9	11	8.5
Secchi	1.7	2.1	3.6	1.4
Temperature °C	-	-	-	-
Highest mean	18	19.2	18.6	17.6
bottom max.	18	18	-	-
O_2 mg/1	7	6	-	sat.[4]
HCO_3	67.6	121	60	-

1. After: Rawson, 1957, 1960
2. After: Koshinsky, 1971
3. After: Cleugh, 1973
4. Saturated most of the year

Table 4.9. Comparison of some Shield Lakes.

	Reindeer[1]	Wollaston[2]	Cree[3]	MacKay[4]	Contact[4]	Little Deer[4]	Hebden[4]	McIntosh[5]
pH surface	7.2	7.2	7.0	7.3	7.3	7.3	7.4	7.1
bottom	6.8	6.8	6.5	6.8	6.7	6.8	6.7	6.6
Cl ppm	0.3	NIL	1.4	14	10	10	3	NIL
SO_4 ppm	2.0	0.6	0.6	2.0	3.0	3.0	3.0	NIL
Si ppm	2.0	0.5	0.4	3.6	1.8	2.8	4.5	1.5
Na ppm	1.8	0.42	2.8	2.2	1.8	3.5	2.4	<5
K ppm	1.1	-	-	0.8	1.7	2.5	1.3	<5
Mg ppm	1.3	7.5	1.0	1.6	5.0	4.1	2.4	1
Ca ppm	2.5	3.6	2.6	5.8	8.0	2.6	4.8	4
Secchi (m)	7.0	6.8	7.8	5.1	5.2	3.8	3.7	4.1
Temperature °C	-	-	-	-	-	-	-	-
Highest $\bar{X}$	13	11.1	14.1	14.5	14.8	18	14.4	18.5
bottom max.	6.5	5.8	10.1	-	-	-	-	-
O_2 mg/l	8.3	9.7	9.3	6.3	6.2	5.8	6.0	-
HCO_3 ppm	15.3	23.6	24.6	29	35	32	37	20

1. After: Armstrong and Schindler, 1971; Rawson; 1959.
2. After: Armstrong and Schindler, 1971; Rawson, 1959.
3. After: Armstrong and Schindler, 1971; Rawson, 1959, 1960.
4. After: Koshinsky, 1965.
5. After: Koshinsky, 1971.

mg/l of sodium; 0.86-0.99 mg/l of potassium; 3.9-4.47 mg/l of magnesium; and 14-16.2 mg/l of calcium.

The 28 March 1973 sampling showed that, on the lakes examined (Rat, Notigi and Wuskwatim), all had higher winter concentrations of cations. The mean concentrations for the lakes ranged from 2.5-2.6 mg/l of sodium; 1.03-1.2 mg/l of potassium; 6.9-8 mg/l of magnesium; and 18.3-24 mg/l of calcium, see Table 4.5. When these values are compared with Churchill River waters and Shield lakes (Tables 4.8 and 4.9), it is evident that upper Churchill lakes have a cation composition generally similar to diversion route lakes while Shield lakes have much lower concentrations of calcium and magnesium. When station 20 on Southern Indian Lake is compared it can be seen that after diversion Ca and Mg will be lower in mainstem waters than in isolated bays.

c. Specific conductance, total dissolved solids and total suspended solids

Winter observations of specific conductance were made on three lakes, (Rat, Notigi, Wuskwatim) on 28 March 1973. The observed values ranged from 135-140 μmho/cm. Conductance decreased in all lakes on the 14 June 1973 sampling, to a range of 88-113 μmho/cm, which may be caused by dilution from ice and snow runoff, which were reported at 90 and 60 μmho/cm respectively. The 18 July sampling showed a large increase in the specific conductance in all the diversion route lakes. The range was 148-173 μmho/cm and these were the maximum values observed in the lakes As total dissolved nitrogen was the only dissolved component to increase dramatically at this time, it is likely that the higher conductivities were caused by organic nitrogenous compounds. August and September values were lower than the July observations at 101-117 μmho/cm, the mean conductance for each lake ranged from 117-130 μmho/cm during the 1973 sampling.

Concentrations of total dissolved solids from the diversion route lakes are recorded in Appendix 4A. The values ranged from 31-130 mg/l and the mean concentrations of each lake ranged from 76-96 mg/l. Mean concentrations of total suspended solids for all lakes, during the 1973 sampling, were always less than 10 mg/l. Winter concentrations of total suspended solids appeared to be lower than summer values at 1-3 mg/l for Notigi, Rat and Wuskwatim Lakes.

After diversion, conductivity, total dissolved solids will decrease in mainstem waters. Total suspended solids will likely increase after diversion (Underwood McClellan 1973).

d. pH values

The hydrogen ion activity of the various lakes are reported in Appendix 4A and Tables 4.5 and 4.7. The lakes are neutral to slightly alkaline, pH 7.1 to 8.2. Summer surface pH values for all the lakes on the diversion route never differed by more than 0.4 pH units (7.8-8.2). The lakes were slightly more acidic on the bottom on 14 June 1973 but as the lakes mixed from wind activity the pH became more homogeneous. Winter surface pH, Table 4.7, were about 0.4 units lower than the summer values, and the bottom winter (28 March 1973) pH values were the lowest observed, 7.1 (Notigi), 7.3 (Rat), and 7.4 (Wuskwatim). These lower pH values are due to respiration-generated carbon dioxide which cannot equilibrate with the atmosphere in winter.

No significant changes are likely to accompany impoundment and diversion except in inundated bays where winter pH values will decline because of biological decomposition releasing CO_2.

e. Chlorophyll-a

Chlorophyll concentrations in the diversion route lakes are repo in Appendix 4A averages and ranges are given in Tables 4.5 to 4.7. Winter (28 March 1973) surface (0.5 m) concentrations for the lakes ranged from 4.1 µg/l (Wuskwatim), 1.2 µg/l (Rat) to 0.8 µg/l (Notigi). The bottom of these lakes had very low winter concentrations of chlorop at 0.4 µg/l (Wuskwatim), 0.3 µg/l (Rat) and 0.1 µg/l (Notigi).

The summer mean chlorophyll range was 1.1-12.1 µg/l, with peak concentrations observed between 18 July and 20 August 1973. Issett 3 µg/l, Karsakuwigamak 3 µg/l, and Rat 3.6 µg/l lakes had the lowest observed summer mean concentrations. Pemichigamau, Notigi, Wapisu and Wuskwatim Lakes had mean summer concentrations between 4.5 and 5.6 µg/ and Mynarski Lake had the highest observed summer average concentratio at 7.3 µg/l. The 14 June chlorophyll concentrations for all lakes measured was 1.1-3.3 µg/l, September 24 also had low concentrations, f all lakes except Mynarski, with a range of 1.4-4.4 µg/l. Mynarski Lal on 24 September had a chlorophyll concentration of 7.2 µg/l.

After diversion and impoundment chlorophyll, as well as other biologically active compounds, suspended and dissolved carbon, nitroger and phosphorus, will reflect changing algal production (see Hecky and Harper 1974).

f. Suspended carbon and dissolved organic carbon

The analytical results for suspended carbon and dissolved organic carbon are recorded in Appendix 4A. The mean concentrations of each diversion route lake are listed in Table 4.5. Suspended carbon (Susp C and dissolved organic carbon (DOC) appeared to vary inversely in concen tration. When Susp C had a high value (mid-summer), DOC was at a corresponding low value, and when Susp C was at the low winter value, DOC was high.

The three lakes (Rat, Notigi and Wuskwatim) measured on 28 March 1973 had Susp C concentrations of 440-580 μg/l. The concentrations of Susp C increased during the summer to an observed peak concentration, in all lakes, during 20 August 1973 of 1010 μg/l in Karsakuwigamak to 2400 μg/l in Mynarski Lake. The Susp C values then decreased during the 24 September 1973 sampling. Karsakuwigamak Lake had the lowest recorded mean concentration of 730 μg/l and Mynarski Lake had the highest mean concentration of 1640 μg/l. The remaining diversion route lakes had mean concentrations of 890-1030 μg/l of suspended carbon.

DOC in the three lakes (Notigi, Rat, Wuskwatim) sampled on 28 March 1973 had a concentration range of 1300-1450 μmoles. The concentration decreased, for all the diversion route lakes, through the summer sampling with a low concentration (520-1258 μmoles) during mid-summer 1973. Karsakuwigamak Lake had the highest mean concentration of 1300 μmoles and Pemichigamau Lake had the lowest mean concentration of 850 μmoles. The mean concentration of DOC for the rest of the diversion route lakes ranged from 970-1100 μmoles.

g. Nitrogen

The diversion route lakes were analyzed for nitrate (NO_3-N), total dissolved nitrogen (TDN) and suspended nitrogen (susp N) during the 1973 sampling. The analytical results are presented in Appendix 4A and mean concentrations, ranges and winter values are recorded in Tables 4.5 to 4.7.

Nitrate analysis for 28 March 1973 sampling indicated a range of

51-96 µg/l for Notigi, Rat and Wuskwatim Lakes. June and July values were much lower, all lakes had concentrations of NO_3-N at 1-5 µg/l. August and September values of NO_3-N were less than 1 µg/l for all diversion route lakes, which may indicate that nitrate was intensively utilized by algal primary production during August and September 1973.

TDN values on 28 March 1973 in Notigi, Rat and Wuskwatim Lakes were 350-480 µg/l. June values of TDN for all diversion route lakes were between 222-290 µg/l and increased dramatically to a peak concentr on 18 July 1973 of 856-1161 µg/l. August values of TDN were 360-545 µg and September was lower than August at 310-403 µg/l. The mean concentration range for all the diversion route lakes for the 1973 sampling was 480-600 µg/l.

Suspended nitrogen had peak values during mid-summer 1973 (18 July - 20 August) of 99-430 µg/l. Mean concentrations for the diversio route lakes (except Mynarski) were between 107-187 µg/l. Mynarski Lake had a relatively high mean concentration at 265 µg/l. The 28 March analytical values for Notigi and Wuskwatim Lakes were 19 and 43 µg/l respectively.

h. Total dissolved phosphorus and suspended phosphorus

Total dissolved phosphorus (TDP) occupied a broad range (<1-35 µg/l) on the diversion routed lakes during 28 March to 24 September 1973. Three lakes were sampled for TDP on 28 March 1973 and analysis showed a concentration range of 23-35 µg/l. TDP decreased through the June and July sampling and 20 August 1973 values were the lowest record for the sampling period (<1-16 µg/l). In four lakes on 20 August 1973 (Mynarski, Wuskwatim, Wapisu and Notigi) the TDP values were less than

1 μg/l, Issett (1972 sample) had 4 μg/l, and Karsakuwigamak, Pemichigam and Rat Lakes had 16, 11 and 12 μg/l respectively. By 30 August all th lakes once again showed similar concentrations of TDP, 9-16 μg/l (Hecky and Harper 1974). The September sampling showed an increase in TDP wit a range of 11-19 μg/l. The mean concentration of all the diversion rou lakes were between 12-19 μg/l for 1973.

Suspended phosphorus (susp P) appeared to have low values during winter, the 28 March 1973 sample analyses were 5-12 μg/l. The concentr of susp P increased in the diversion route lakes through June and July and peak concentrations (18-33 μg/l) were observed in all the lakes dur 20 August 1973. The values decreased during the September sampling to 13-24 μg/l. Mynarski and Wapisu Lakes had the highest mean concentrati (21-22 μg/l) of susp P while Wuskwatim, Notigi and Rat Lakes had 18.5, and 16 μg/l respectively. Karsakuwigamak and Pemichigamau Lakes had th low mean concentration for the 1973 sampling at 14 μg/l.

4.4. Phosphorus loading, Wuskwatim Lake, 1973 :

Phosphorus loading rates were calculated for Wuskwatim Lake in or to get a quantitative measurement of organic production on the diversio route. Incomplete monthly data dictated chemical concentration extra- for most of the winter months. Estimated concentrations and loadi are presented in Tables 4.10 and 4.11. Loading was computed as follows

$$\text{Loading (g/sec)} = \frac{\text{Discharge (cfs)}}{1000} \times 1 \; \frac{28.31}{\text{cfs}} \times \text{concentration (mg/}$$

Yearly loading for Wuskwatim Lake for 1973 is computed as follows

TDP 1.848 x seconds/year = 58×10^3 kgms

Susp P 1.193 x seconds/year = 38×10^3 kgms

Total P 3.041 x seconds/year = 96×10^3 kgms

Annual areal loading of total phosphorus in Wuskwatim Lake i as follows: (Area of Wuskwatim = 46.43 km^2, $\bar{x}$ depth = 6.24 m)

$$L = \frac{96 \times 10^3 \text{ kgms P/yr}}{45.4 \text{ km}^2} = 2.1 \text{ gms P/m}^2\text{/yr}$$

Figure 4.5 (after Vollenweider, 1968) would indica the lake could be highly eutrophic if nutrients were the only consid But, as noted for Southern Indian Lake and the lower Churchill lakes (Cleugh 1974) and Hecky and Harper (1974) nutrient loading is not th primary determinant of algal production in these riverine lakes. Turbidity, limiting light, and low turnover times, retarding nutrien utilization, violate some of the assumptions required for the use of Fig.4.5 (Vollenweider, 1968). It does demonstrate however that there are abundant nutrients presently and loading associated with higher charge after the Churchill River diversion will not necessarily incr the nutrient availability in the new Rat-Notigi reservoir which will have an estimated loading of 1.4 g P/m^2/yr at a mean depth of 7.1 m (assuming mean annual discharge of 31,170 cfs and phosphorus concent similar to station 20 in Southern Indian Lake).

4.5. Impact of impoundment:

The hydroelectric development of the diversion route lakes at Notigi Lake will result in a single large lake with a greatly increa

Table 4.10 Estimated mean monthly values of phosphorus, Wuskwatim Lake, 1973.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Flow*	1080	914	800	894	5933	7715	5991	4012	3626	2801	2172	1514
TDP$^+$	25	25	30	25	22	20	20	<1	15	15	18	20
Susp P$^+$	8	10	12	13	14	15	18	21	21	15	9	6

* mean monthly flow in cfs, Wuskwatim Rapids (Water Resources 1973)

+ values in μg/l

Table 4.11. Estimated phosphorus loading, Wuskwatim Lake, 1973

	Winter (Oct-Apr) $\bar{x}$ D = 1454 cfs		Summer (May-Sept) $\bar{x}$ D = 5455 cfs		Annual $\bar{x}$ D = 3121 cfs	
	$\bar{x}$ conc.	Loading gm/sec	$\bar{x}$ conc	Loading gm/sec	$\bar{x}$ conc.	Loading gm/sec
TDP	22.57	0.929	18.6	2.873	20.92	1.848
Susp P	10.43	0.429	17.8	2.749	13.5	1.193
Total P	33.0	1.358	36.4	5.622	34.42	3.041

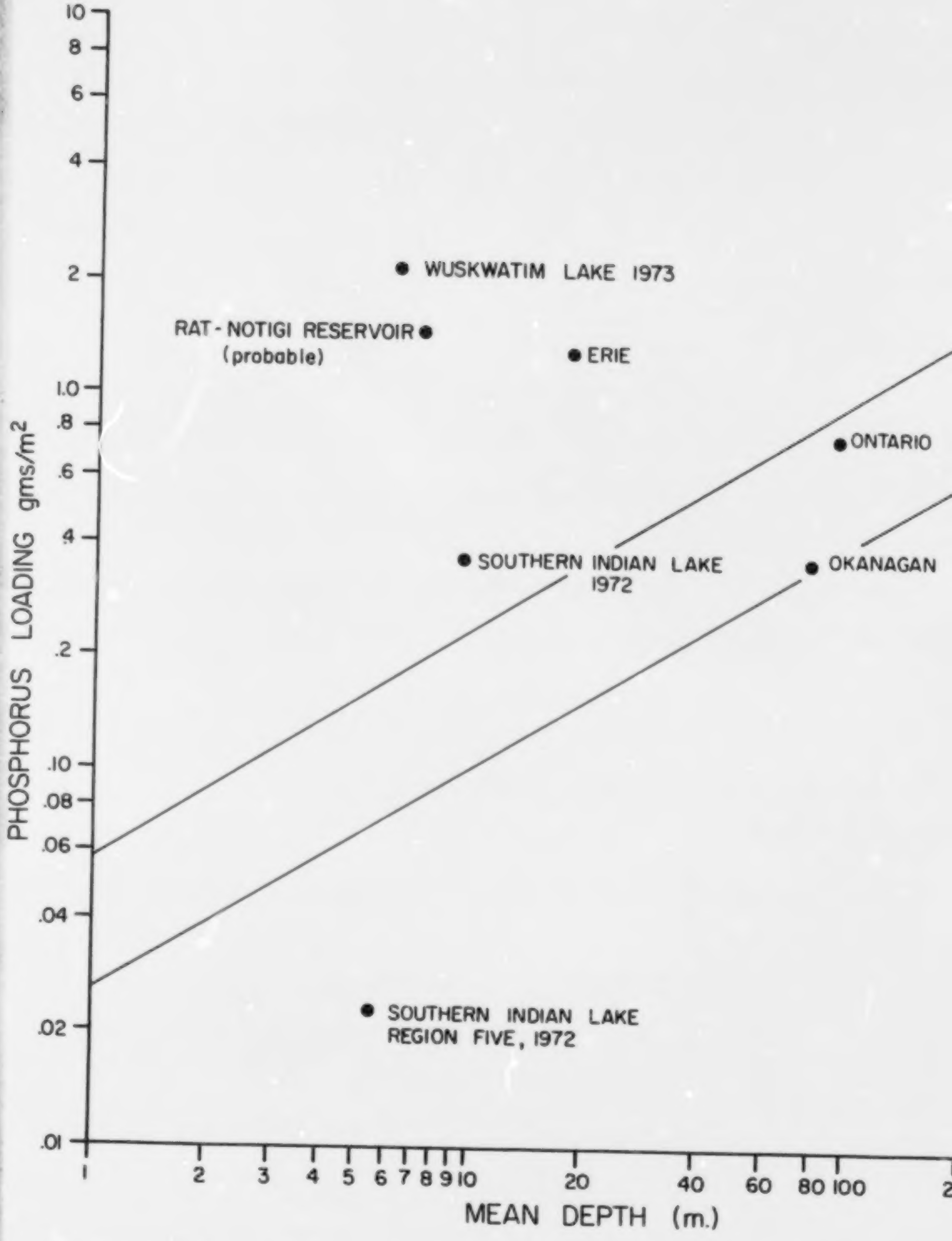

Figure 4.5 Annual total phosphorus loading of Wuskwatim Lake, 1973
to other North American Lakes.

discharge. Impact of this development on the chemical and physical environment will be significant. Erosion, in the new impoundment of the glacio-lacustrine clay shorelines by wave wash will greatly increase the turbidity until the new shoreline stabilizes. Wind induced water currents will spread large plumes offshore into the main mass of the lake. The erosion will be severe during flooding in the spring and during annual drawdown. The timber covered areas may have less severe erosion but stabilization will take much longer. Siltation is likely to be especially severe during the first 10 years, with turbidity generally declining through a much longer period. Probable effects of siltation and turbidity on aquatic organisms are considered in other reports by the Fisheries-Limnology component.

Swan Bay, an elongated area of South Bay in Southern Indian Lake, is currently undergoing severe shoreline erosion and may be a comparable area, see Cleugh 1973. The effects of shoreline erosion and consequential turbidity are evident throughout the bay with low transparency, 0.1 m, and wind generated plumes of clay are visible extending into the main South Bay water mass. Most of the investigated biological parameters including fish production for this region were also much lower than Southern Indian Lake proper.

Mean depth of the Rat-Notigi reservoir will be approximately 7.1 m and summer thermal stratification will not be extensive or prolonged as river currents and wind action will tend to keep the reservoir isothermal. However, thermal stratification is likely under ice, and the large inundated areas with biological decomposition will likely create oxygen depletions which will be especially severe in bays off the mainstem reservoir. Winter oxygen conditions will improve as organic soils are buried by sediments or are mineralized, but data from Kettle Reservoir indicate that low oxygen conditions can persist at least 10 years after impoundment.

The flooding of organic soils and erosion of the shoreline will release nutrients into the water. The nutrients even if biologically available are unlikely to increase primary production markedly as nutrient loading by the Churchill River will be quite high. More significant will be sediments added from eroding shorelines which will degrade the transmissivity of inflowing Churchill River water which has a greater Secchi disc depth than the present Rat River. Conditions in the upper reservoir in the vicinity of the diversion channel are likely to be especially severe as the shallow depths will not allow materials to settle below the depth of active wind mixing. Below the Rat-Notigi Reservoir where active channel cutting will occur there will be at least a fourfold increase in total suspended solids over the natural condition, and this will greatly reduce light penetration in Wapisu, Threepoint and Wuskwatim (Underwood & McClellan 1973).

4.6. Summary:

1. The diversion route lakes had a high rate of heating and cooling, and were isothermal in summer. Maximum recorded temperature was 20 C.

2. Dissolved oxygen concentrations were low after ice-out and in deep waters during the winter, otherwise the lakes had saturated oxygen levels.

3. The lakes were relatively untransparent in 1973, with a Secchi range of 0.5-2.5 meters.

4. The chemical parameters measured were relatively uniform in distribution between all the diversion route lakes during each sampling.

5. Phosphorus loading rate for Wuskwatim Lake was 2.1 gms/m^2/yr for 1973, indicating that the lake receives an abundance of nutrients.

6. The diversion route lakes and station 20 on Southern Indian Lake are chemically similar with the exception of total inorganic carbon, calcium, and magnesium which have higher concentrations in the diversion route lakes.

7. Some oxygen depletion will occur from oxidation of flooded organic soils, especially in shallow areas and bays during winter ice-cover conditions.

8. Severe turbidity will occur from wave action on the glacio-lacustrine clays until the new shoreline stabilizes. Increased turbidity will lower the visibility in inflowing Churchill River water.

9. Thermal stratification especially in ice-cover conditions, may occur in the new reservoir aggravating winter oxygen depletion.

10. Erosion due to increased flows (8-10 times) will reduce productivity in the lakes below the Rat-Notigi Reservoir due to extremely high turbidities and low turnover times.

5. THE NELSON RIVER AND RESERVOIRS

5.1. Physiography, climate, geology:

The Nelson is the largest river in the province of Manitoba with an average flow, at its approximate mid point, of 75,000 cfs. It flows approximately 400 miles from Lake Winnipeg (its source) to Hudson Bay, and drains an area of 414,000 square miles including Alberta, Saskatchewan, Manitoba and to a lesser degree, Ontario and several of the United States. The river flows through the Precambrian Shield, in the upper Nelson and through Paleozic limestone in the lower Nelson. The upper Nelson basin is covered by lenses of glacio-lacustrine clays of varying depth while the lower Nelson has marine sediments as overburden. The approximate boundary of the upper and lower Nelson is about 10 miles east of Gillam.

Daily mean temperatures for July range from 58-64° F while January temperatures average -13°F respectively. Annual mean temperature is between 20-28°F for the study area. Mean date for lake freeze-over is November 1, the rivers are about 10 days later (November 10). The approximate dates for ice clearing are May 1 - June 1 for the rivers and June 10 for the lakes. Annual precipitation is 16", one third of which falls as snow (Weir 1960).

5.2. Hydro proposal:

Manitoba Hydro (personal communication April 3, 1973) estimates possible final profile for the study area of 10 impoundments and 2 diversion canals for the Nelson River, 4 impoundments on the Rat-Burntwood system and one impoundment and one diversion canal on Southern Indian Lake, see Tables 5.1 and 5.2. Two impoundments (Kelsey and Kettle) are completed or near completion, one (Jenpeg) is under construction, and the two diversion canals (Playgreen Lake) are also undergoing excavation on the Nelson River. Notigi Lake (on the Rat River) and Missi Falls (on Southern Indian Lake) impoundments are under construction as well as the diversion canal at South Bay.

5.3. Morphometry of mainstem lakes:

The Nelson River discharges from its source at Playgreen Lake at two locations, the East and West Channels. Both flow north and discharge into the southwest corner of Cross Lake. The lake has two other major inflowing rivers, Minago and Walker, and numerous minor streams. The Nelson River discharges from Cross Lake and flows into Sipiwesk Lake 15-20 miles to the north.

Cross Lake is on the Precambrian Shield with the basic rock type being granite. Surficial deposits are glacial lacustrine clays and existing soil is grey wooded podzol. Marsh and bogs are common, especially around the western half of the lake (Diver & Doan 1972, Weir 1960).

The surface area is 296 square miles at 679 feet above mean sea level. Mean depth is 11 feet and maximum reported depth is 85 feet (see Diver and Doan for bathymetric map).

Sipiwesk Lake (55°05'N - 97°35'W) is a Nelson River mainstem lake. It is located on the Precambrian Shield approximately 50 miles south of Thompson, Manitoba. The surficial deposits are glacial lacustrine clays and the thin layer of soil is grey-wooded podzol.

Table 5.1 Projected Manitoba Hydro development on the Nelson River

Location	Completion date	Elevation (feet)	Miles from Lake Winnipeg	Head Height (feet)	Develop
Playgreen Lake	1974	711-715	0	-	Diversio
	1974		25		Diversio
Jenpeg*	1974	713	75	25	Impoundm
Bladder	1994	680	120	61	Impoundm
Kelsey	completed	605	230	50	Impoundme
Upper Gull	1995	553	275	46	Impoundme
Lower Gull	1995	505	290	45	Impoundme
Kettle	completed	458	315	98	Impoundme
Long Spruce	1977	358	330	80	Impoundme
Upper Limestone	1982	275	345	80	Impoundme
Lower Limestone	1985	190	355	80	Impoundme
Gillam Island	1987	110	395	80	Impoundme

* An east channel Nelson River control impoundment is also under consideration by Hydro.

Table 5.2. Projected Manitoba Hydro **development** on Southern Indian Lake and the Rat-Burntwood Rivers.

Location	Completion Date	Elevation (feet)	Miles from Southern Indian Lake	Head Height (feet)	D
Missi Falls	1975	850	0	< 20	I
South Bay	1975	850	0	-	D
Notigi	1975	850	80	≈ 50	In
Wuskwatim	1990	800	130	93	In
Manasan	1991	670	160	58	In
First Rapids	1991	610	220	55	In

Mean temperature ranges for July and January are 60-64°F and -10 to -16°F respectively. Sipiwesk Lake has 80-90 frost-free days and 1,600°-1,800° days above 43 F, annual precipitation is 17-18 inches, one third of which falls as snow (Weir 1960).

The lake has an area of 151.8 square miles and 1,100 miles of shoreline at 608 feet elevation. Mean depth is 35.5 feet and maximum recorded depth is 130 feet. There are many small islands throughout the lake and several fairly large islands (Schlick 1968; Newbury 1973).

The Nelson River discharges in two locations at the southwest of Sipiwesk Lake and flows out northeast of the lake. There are twelve other major streams that flow into Sipiwesk Lake and a large number of smaller streams.

In 1960 Manitoba Hydro impounded Sipiwesk Lake and increased the lake level by 7.5 feet (mean) with a mean annual lake level fluctuation of 4.8 feet at Kelsey generating station. The total flooded area was less than 10 square miles. The primary physical impact on the lake was slight to moderate (vegetation killed and erosion) on 45% of the lake an severe (vegetation killed, erosion and undercutting) on 50% of the lake (Newbury 1973).

Split Lake is a mainstem (see Koshinsky 1971) lake of the Nelson River, at approximately 56°08'N by 96°15'W. Most of the shoreline (262 miles) is exposed bedrock, with thin overburden of lacustrine clays and s (Newbury, 1973). There are also extensive bog and marsh areas, the soil is grey-brown podzol. The vegetation is predominantly black spruce. The mean July temperature is 59°F and the mean January temperature is -15°F. There are 70-80 frost-free days and 1,200-1,600 degree days at 43°F or higher (Weir 1960). The mean lake depth is 18.3 feet and the maximum dep is 98 feet (Schlick 1968). The lake has an area of 187.8 square miles at 545 feet above mean sea level, and a total volume of 2.92 x 10^9 cub meters. Schlick (1968) gives a morphometric map of the lake.

There are several major rivers, besides the Nelson, that discha into Split Lake. The Grass River, immediately below the Kelsey Dam on the Nelson River, and the Odei and Burntwood Rivers enter Split Lake f the west. The Aiken and Ripple Rivers flow into Split Lake from the southeast. Split Lake drains into Clark Lake which is also a Nelson mainstem lake.

There are two settlements on Split Lake with approximately 400- people. The main industry is commercial fishing.

The Nelson River was impounded at the Kettle Rapids, near Gilla and raised in two stages in the autumns of 1970 and 1971, flooding approximately 125 square miles. The dam head of water is 98 feet and floods the Nelson River back to a minimum of 43 feet at Gull Rapids, w a mean annual drawdown of approximately five feet. Impact was severe on 95% of the inundated area, with drowned vegetation and severe solifluction and erosion. The flooding caused shoreline undercutting due wave action, slumping and widespread unstable areas due to extensive melting of permafrost, floating peat islands and flooded vegetation an severe erosion of islands and shoreline overburden banks (Newbury 1973

5.4. Hydrology:

Hydrological data for the Nelson River at Kelsey Dam, from July 1960 to December 1973, has been recorded by Manitoba Hydro, and is presented in Table 5.3. Mean monthly flow for the 13 years is 86,900 cfs, average monthly summer flows is 104,052 cfs and average monthly winter (November-April) flow is 69,782 cfs.

The mean monthly flow at Wuskwatim Rapids, Burntwood River, is 3,121 cfs, the minimum and maximum mean monthly flows are 242 cfs and 15,746 cfs respectively, see Table 5.4. After diversion of the Church River the average monthly flow will be 31,170 cfs, with probable absol minimum and maximum flows of 7,718 cfs and 34,000 cfs. The monthly fl of the new regime are given in Table 5.5 and were estimated by Manitob Water Resources.

5.5. Field observations:

a. Thermal regime

Temperature profiles from each observation are shown in Table 5 The maximum observed temperature on the Nelson River was 21.5°C on 21 August 1973. No thermal stratification was observed. The Burntwood had a maximum temperature of 20.2°C also on 21 August 1973. Moose Cre (station 4) had a slight thermocline throughout the sampling period. maximum recorded gradient was 3.7°C on 1 August 1972, a winter stratif cation of 0° to 3°C was recorded on 25 March 1973. The maximum observ temperature was 18.8°C also on 21 August 1973.

b. Oxygen

Dissolved oxygen observations were taken in conjunction with temperature profiles. Oxygen observations are shown in Table 5.6. Nelson and Burntwood Rivers dissolved oxygen (except for the June samp were always greater than 80% saturation, with a range of 80-120%. Dur the June sampling (immediately after ice-out) the dissolved oxygen lev

Table 5.3 . Hydrology of the Nelson River at Kelsey, July 1960 to December 1973, in cfs.

	January	February	March	April	May	June	July	
imum	34390	31300	28600	27650	58470	68450	65560	
rage	66500	64120	64890	67740	96520	109280	113150	
imum	90140	89000	88600	93300	126000	155200	169500	
	August	**Sept**	**October**	**November**	**December**	**Summer (May-Oct)**	**Winter (Nov-Apr)**	**Annual**
imum	63450	56540	57600	47340	35870	61678	34192	51500
rage	106910	102830	95620	84020	71420	104052	69782	86900
imum	160000	143300	129600	108100	102100	147267	95207	115000

Table **5.4** Historic mean monthly flow (cfs) data at Wuskwatim Rapids, 1928-1966.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Minimum	293	260	242	264	1967	1578	493	920	360	482	545	425	242
Mean	1080	914	800	894	5933	7715	5991	4012	3626	2801	2172	1514	3121
Maximum	2202	1935	1778	2563	10733	15746	11776	11309	9654	6875	4438	2730	15746

Table **5.5** Mean monthly flows (cfs) after impoundment and diversion.

	Jan.	Feb.	Mar.	Apr.	May.	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Minimum	17042	7990	17767	7718	10841	31041	34000	32736	24683	25060	19876	17781	7718
Mean	29457	28295	27429	26519	32120	33991	34000	33937	33384	32562	32056	30286	31170
Maximum	32461	32405	32119	32258	34000	34000	34000	34000	34000	34000	34000	33145	34000

ranged from 30-71% of saturation. No stratification was observ
had much lower oxygen concentrations. Oxygen saturation value
from 51-100% at 0.5 m and 24-63% at the bottom, except during
and 13 June samplings. During these samplings the dissolved o
25 and 20% respectively, at 0.5 meters.

c. Transparency

The Nelson River Secchi depth was always less than one
a range of 0.2-0.9 meters over the sampling period (Table 5.7)
Burntwood River (station 200) had a constant 0.3 m Secchi duri
sampling period, and Moose Creek (station 4) was relatively tr
with a Secchi range of 1.5-2.6 m. The low transparency of the
River probably results from the fine suspended clays being tra
by the river currents.

d. Ice

Depth of ice was recorded at each station sampled durin
trips, and recorded in Table 5.8. Stations 3 and 5 did not fr
during the winter of 1972-73, probably because of the fast cur
resulting turbulence

5.6. Chemical analyses:

The complete results of water chemistry analyses are re
Appendix 5A. A summary of annual range, summer and winter mea
means of all analyses for all parameters at each station are r
in Table 5.9. A comparison with other Shield lakes is present
5.10. Appendices 5B and 5C demonstrate graphically each chemi
on a station to time to concentration basis. Location of the
indicated on Figure 1.1.

Table 5.6 Summary of temperature (°C) and dissolved oxygen (%) on the Nelson River.

Station			240	1'	1	2'	2	200	3	4	4'	5	5'	195
30 May 1972	Temp	- 0.5 m			8.5		8.2	8.1				4.5		
		- bottom			8.3		8.2	-				4.5		
22 June, 1972	Temp	- 0.5 m			14.5		14		13.5	10.5		13		
		- bottom			13		14		13	9.8		12.8		
12 July, 1972	Temp	- 0.5 m			16.2		16.2		15.5	14.2	16	16		
		- bottom			16		-		15.5	13.8	15.9	16		
	O_2	- 0.5			97		101		98	60	99	105		
		- bottom			97		-		-	63	99	-		
1 August 1972	Temp	- 0.5 m			17.2		17.3		17.1	15.9	17.4	17		
		- bottom			17.2		-		17.1	12.2	17.2	-		
	O_2	- 0.5 m			96		101		99	68	99	101		
		- bottom			96		-		-	56	99	-		
21 August 1972	Temp	- 0.5 m		17.2	18.5		17.2	19.1	17	16.7	17.6	17	16.2	18.0
		- bottom		17.2	17.4		17.2	19.1	17	16	17	17	16.2	18.0
	O_2	- 0.5 m		97	101		100	102	98	60	100	104	97	104
12 Sept 1972	Temp	- 0.5 m			13.2		13.2	10.5	12.5	12.5	12.5	12.2		10.8
		- bottom			13.1		13.2	-	12.5	10.8	12.4	12.2		10.8
	O_2	- 0.5 m			90		96	98	97	83	98	105		99
		- bottom			87		-	-	97	63	96	105		-
4 October 1972	Temp	- 0.5 m			6.0		6	5.7	5.7	7	5.7	5.7		
		- bottom			6.0		6	-	5.7	5.5	5.7	5.7		
	O_2	- 0.5 m			-		-	-	-	-	-	-		
		- bottom			-		-	-	-	-	-	-		

Table 5.6 cont.

14 Dec 1972	Temp	- 0.5 m				3	1	-	1	3	2	0
		- bottom				-	1	-	1	-	2	0
	0_2	- 0.5 m				84	92	-	110	100	107	104
		- bottom				-	92	-	110	-	-	-
28 Feb 1973	Temp	= 0.5 m		0					0			
	-	- bottom		-					-			
	0_2	- 0.5 m		105					100			
		- bottom		-					-			
25 March 1972	Temp	- 0.5 m			0	0	0	0	0	0	0	0
		- bottom			0	0	0	0	0	3	0	0
	0_2	- 0.5 m			8	-	95	108	120	25	100	110
		- bottom			-	-	-	-	-	-	-	-
13 June 1973	Temp	- 0.5 m	13	13			12.3	12		8	11.8	
		- bottom	-	-			12.3	12		-	11.6	
	0_2	- 0.5 m	42	30			34	50		20	71	
		- bottom	-	-			-	-		-	-	
16 July 1973	Temp	- 0.5 m	17.9	17.5			17.2	18		17	16.1	
		- bottom	-	-			17.2	18		15	16.1	
	0_2	- 0.5 m	120	104			82	83		51	80	
		- bottom	-	-			-	-		24	83	
21 August 1973	Temp	- 0.5 m	20.2	20.8			21.5	20.2		18.8	20.2	
		- bottom	-	-			21.5	-		18.0	20.2	
	0_2	- 0.5 m	110	110			112	110		76	110	
		- bottom	-	-			112	-		-	100	
26 Sept 1973	Temp	- 0.5 m	9.6	10			10.6	9.1		9.1	10.1	10
		- bottom	-	-			10.6	9.1		-	-	10
	0_2	- 0.5 m	120	120			120	120		100	120	120
		- bottom	-	-			-	-		-	-	120

Table 5.7 A comparison of Secchi disc transparency on the Nelson River, 1972-73 (meters).

Station	240	1'	1	2	200	3	4	4'	5	5
1972 May 30	-	-	.9	.9	-	-	-	-	.5	-
June 22	-	-	.2	.2	-	.2	1.5	-	.5	-
July 12	-	-	.3	.3	-	.3	-	.3	.3	-
August 1	-	-	.3	.2	-	.2	1.5	.3	.4	-
August 21	-	.5	.7	.5	.3	.3	1.8	.4	.5	.5
Sept 12	-	-	.9	.6	.3	.6	2.6	.8	.8	-
October 4	-	-	.3	.3	.3	.3	1.8	.5	.3	-
1973 June 13	.3	.9	-	.9	.3	-	2.5	.8	-	-
July 16	.5	.5	-	.5	.3	-	2.5	.7	-	-
August 21	.7	.5	-	.6	.3	-	2	.8	-	-
Sept 26	.5	.5	-	.5	.3	-	1.6	.8	.9	-

Table 5.8 A comparison of ice thickness (inches) on the Nelson River, 1972-73.

	240	1'	2	3	4	4'	5
1972							
December 14	25	-	OP.W.*	OP.W.	14	24	OP.W.
1973							
February 28	-	36	-	OP.W. 39 in bays	36	36	OP.W.
March 25	36	-	45	OP.W.	48	-	OP.W. over 60 in bays

* OP.W. = open water at sampling site.

a. Anions

Chloride occupied a narrow range on the Nelson River of 14-22 mg/l which is considerably higher than the chloride concentrations reported for the Churchill River of 1 mg/l (Cleugh 1974). Chloride values remained relatively invariable in summer and winter analysis. The Grass (2') and Burntwood Rivers (200) had a range of 1-6 mg/l and Moose Creek (4) was also relatively low at 3-7 mg/l chloride during 1972-73.

Silicon concentration range on the Nelson River was 0.17-1.7 mg/l over the sampling period. Winter values, up to the beginning of June, were low, usually less than 0.4 mg/l. Peak concentrations were observed in mid-summer, July to August, then decreased during fall and winter samplings. No silicon pulse through the Nelson system was observed as shown in Southern Indian Lake (Cleugh 1974). The samples from Grass River (station 2') indicate a much higher (2.2 mg/l) silicon concentration for its drainage basin. The Burntwood River (stations 195, 200) also show a higher (1.7 mg/l) silicon input. The high value (5.6 mg/l) at station 196 is due to the close proximity of the Thompson sewage outlet. Moose Creek (station 4) had a concentration range of 1.23-2.3 mg/l of silicon throughout the sample period. Observed values, unlike the cyclic values observed on the Nelson, tended to be constant, no summer high and winter low concentrations were observed.

Sulfate (SO_4) concentrations were relatively uniform throughout the Nelson River during the sampling period, with a summer (April-September) range of 17-27 mg/l and a winter range of 23-40 mg/l. The mean concentration is considerably higher than the Churchill River at Southern Indian Lake which had a 1972-73 mean SO_4 value of 4 mg/l (Cleugh 1974). The Grass and Burntwood Rivers had a summer range of 5-9 mg/l

SO_4, no winter observations were taken. Moose Creek also had a lower SO_4 range at 9-16 mg/l for the summers of 1972 and 1973.

Inorganic carbon (CO_2) analysis for the 1972-73 field sampling are recorded in Appendix 5A. The Nelson River had a range of 1206-2645 μmoles. Higher values were recorded during the winter sampling and low concentrations of CO_2 were recorded in the ice-free season. The lowest recorded values were observed immediately after ice-out, in early June. The Moose Creek sampling showed a slightly higher concentration of total CO_2 than the Nelson River with a range of 1,329-2,584 μmoles. The Burntwood River CO_2 values were slightly less than the Nelson River with a range of 851-1,899 μmoles.

b. Cations

Calcium had a range of 22-34 mg/l on the Nelson River during the sampling period. Moose Creek appeared to be similar in concentration of Ca to the Nelson River. No trends were observed. The Burntwood River had lower calcium concentrations with a range of 15-21 mg/l over the sampling period, 1972-73. Calcium concentrations on the Churchill River at Southern Indian Lake were only 1/3 of the Nelson Ca values at 8.5-9.4 mg/l.

Magnesium analysis are presented in Appendix 5A, a range of 8.1-13.8 mg/l was recorded for the Nelson River. Churchill River water, at Southern Indian Lake, had a lower recorded mean concentration of Mg at 3.9 mg/l. Moose Creek had a low recorded Mg range of 6.6-10.7 mg/l and Burntwood River Mg concentrations were also relatively low with a range of 4.3-7.2 mg/l.

The 1972-73 concentration range of potassium (K) on the Nelson

River was 2.1-4.2 mg/l, twice the value observed on the Churchill River of 1.1-1.3 mg/l (Cleugh 1974). Winter (March) concentrations of K were higher than the summer recorded values at all stations. The Burntwood River K values were similar to the Churchill River with a range of 1.09-1.9 mg/l. The Moose Creek samples, which probably reflect the local stream leaching, was also lower in K with a concentration range of 1.5-2.6 mg/l over the sampling period.

The Nelson River, 1972-73, concentration range was 9.5-17.2 mg/l of sodium (Na). Recorded values were higher during winter sampling at all stations, with peak concentrations of Na occurring during the March sampling. Moose Creek observed values ranged from 5.5-10.4 mg/l. Summer concentrations were lower than winter values, with a peak in March and the lowest recorded values of Na in June, July and August. The Burntwood River summer (May-September) concentration of Na ranged from 3.4-4.4 mg/l. The winter recorded value during March was 10.1 mg/l. The Churchill River annual mean at Missi was 2.5 mg/l, much lower than the Nelson drainage system.

Chlorophyll-a measurements taken are presented in Appendix 5A, means and ranges in Chl-a concentrations are shown in Table 5.9. All the stations in the study are located on the Nelson River, or one of its major tributaries. Therefore, chlorophyll analysis does not necessarily reflect the productivity at the sampling station, but may be an indication of upstream productivity. The analysis showed very low winter values, due to lower temperatures and limited light transparency due to ice and snow covering. Moose Creek and the Burntwood River generally had lower chlorophyll values than the Nelson River. The peak values were recorded during July and August.

The Nelson River hydrogen ion activity during the summer (May-September) was 8-8.5 pH units. The winter recorded pH range was 7.7-8. The Burntwood River had a similar pH range to the Nelson River at 7.6-8.3. Moose Creek was consistently lower with a pH range of 7.1-7.9. Individual observations are recorded in Appendix 5A.

Specific conductance on the Nelson River during 1972-1973 range 206-330 μmho/cm. Conductance was low during ice-out with a range of 221-284 μmho/cm, which increased through summer, fall and winter to a peak during March of 280-330 μmho/cm. The Grass and Burntwood Rivers were much lower with a conductance range of 119-190 μmho/cm. Moose Creek was also relatively low with a range of 194-280 μmho/cm, the May-September range was 194-242 μmho/cm.

Total suspended solids on the Grass River and Moose Creek were always less than 10 mg/l during the sampling period. The Burntwood and Nelson Rivers were less than 10 mg/l during the winter sampling, but increased in the summer observations to 10-20 mg/l TSS. The peak concentrations were observed during July and August samplings.

Total dissolved solids (TDS) on the Nelson River ranged from 110-221 mg/l through the 1972-73 sampling period. Concentrations of winter TDS were considerably higher than during summer. Winter (December-March) values ranged 181-221 mg/l, concentration of TDS were much lower in May, immediately after ice-out, at 120-140 mg/l, then increased in concentration through the summer and fall to the winter peak. Moose Creek had lower TDS values at 110-192 mg/l and the Grass and Burntwood Rivers were also lower than the Nelson, at 40-160 mg/l. Winter TDS values on these major tributaries were also higher than summer values. Mean concentration on the Churchill River at Southern Indian Lake was 69 mg/l during 1972 (Cleugh 1974).

Nitrate (NO_3-N) values in winter were relatively high due to limited production. Summer (May-September) concentration in 1972 ranged from 2-30 μg/l with a mean of 16 μg/l. Therefore NO_3-N was likely not a limiting nutrient in the Nelson River during 1972. However, during 1973, NO_3-N values were relatively high during March (9-44 μg/l) but decreased to 0-2 μg/l during the June sampling. The June-July period had a mean concentration of 1 μg/l for the Nelson River, and may have been limiting nutrient for primary production. The Grass and Burntwood Rivers and Moose Creek all had greater concentrations of NO_3-N, with a range of <1-139 μg/l. During 1973 low concentration (1-5 μg/l) of NO_3-N were also recorded on the Burntwood River and Moose Creek.

Total dissolved nitrogen (TDN) had a range of 300-520 μg/l on the Nelson during 1972-73. Concentrations were relatively much higher on the three major tributaries. Moose Creek had a range of 400-639 μg/l, and the Burntwood River had a range of 356-680 μg/l.

Suspended nitrogen (susp N) had lower observed winter concentration on the Nelson River with a range of 25-61 μg/l, and a higher summer range of 30-139 μg/l. The major tributaries had an annual range of 30-128 μg/l. The Churchill River appears to have similar concentrations of susp N (Cleugh 1974) to the Nelson River.

Suspended phosphorus (susp P) had a range of 9-26 μg/l during the sampling period on the Nelson River. Winter and summer concentrations of susp P were relatively similar, no distinct trends were observed. The Burntwood River had a slightly higher annual mean concentration of susp P with a range of 11-23 μg/l. Moose Creek had a concentration range of 6-31 μg/l.

Total dissolved phosphorus (TDP) on the Nelson River had a range of 1-41 μg/l. Concentrations of TDP were lowest during the summer sampl on the upper Nelson during the August 21, 1973 values of 1 μg/l were observed. Grass and Burntwood Rivers had similar concentrations of TDP as the Nelson River. Moose Creek, a newly flooded area (1971), had a much higher concentration of TDP than the Nelson River at 28-101 μg/l. This large concentration of TDP could be due to leaching of a newly inundated area.

5.7. Phosphorus loading Split Lake:

Nutrient loading rates were calculated for Split Lake in order to get a quantitative measurement of the potential availability of nutrient on the Nelson River. Incomplete data dictated chemical concentration extrapolation for some months. Estimated concentrations and loading for pre- and post-diversion are presented in Tables 5.11 to 5.13. Loading was computed as follows:

$$\text{Loading (gm/sec)} = \frac{\text{Discharge cfs}}{1000} \times \frac{28.31}{1 \text{ cfs}} \times \text{phosphorus in mg/l}$$

Annual loading is computed as follows:

Pre-diversion: Total P = 172.167 gm/sec = 5.43×10^6 kgms/yr

Post-diversion: Total P = 187-692 gm/sec = $5{,}92 \times 10^6$ kgms/yr

Annual areal loading of total phosphorus for Split Lake is computed as follows:

(Area = 486 km^2, depth = 6 m)

$$\text{Pre-diversion is } L = \frac{2.7 \times 10^9 \text{ gms/yr}}{486 \times 10^6} = 5.5 \text{ gms P/m}^2\text{/yr}$$

Figure 5.1 indicates that Split Lake has a high loading rate relative to other, well studied Canadian lakes. This high loading rate is offset by the low turnover times for the water in the lake and high turbidity so the lake is not as productive as might be expected from considering phosphorus loading alone. Phosphorus loading will increase by at least 22% by diversion, but this is unlikely to lead to increased productivity.

5.8. Impact:

The increased flow will increase turbidity from erosion of the Burntwood River banks. The increased flow will also increase the lake level of Split Lake, which could increase turbidity from shoreline erosio The erosion and subsequent increased nutrient loading will be short-term effects of diversion.

Station 4, Moose Creek, was investigated in order to study the impact of flooding in the study area. Station 4^1 on the Nelson River was used as a control. Increased TDN and TDP, over the Nelson River, were evident throughout the sampling period. Averages of TDN and TDP for station 4 were 522.4 μg/l and 58 μg/l respectively, and for station 4^1 were 384.4 μg/l and 23.9 μg/l respectively. Decreased oxygen saturatio

Table 5.9 A comparison of means and ranges by station, Nelson River Study, 1972-73.

Total CO_2	Total inorganic carbon	μmoles/l
Cl	Chlorate	mg/l
SO_4	Sulfate	mg/l
Si	Silicon	mg/l
Na	Sodium	mg/l
K	Potassium	mg/l
Mg	Magnesium	mg/l
Ca	Calcium	mg/l
Mn	Manganese	mg/l
Fe	Total iron	mg/l
NO_3-N	Nitrate	μg/l
TDN	Total dissolved nitrogen	μg/l
Susp N	Suspended nitrogen	μg/l
TDP	Total dissolved phosphorus	μg/l
Susp P	Suspended phosphorus	μg/l
Chl a	Chlorophyll a	μg/l
Cond	Conductivity	μmho/cm
pH	Hydrogen ion activity	pH units
TDS	Total dissolved solids	mg/l
TSS	Total suspended solids	mg/l
Susp C	Suspended carbon	μg/l
DOC	Dissolved organic carbon	μmole/l
Cu	Copper	μg/l
Zn	Zinc	μg/l
Cd	Cadmium	μg/l
Pb	Turbidity	ppm

For station location see Figure 1.1.

Station 240

Chemical species	Range	Summer $\bar{x}$ (May - Sept.)	Winter $\bar{x}$ (Oct - April)	Annual $\bar{x}$
NO_3-N	1 - 9	3.25		
TDN	324 -425	382		
Susp N	32 -139	94.8		
TDP	1 - 25	16.3		
Susp P	15 - 23	18.3		
Chl	1.6- 2.9	2.6		
Cond	262 -295	277		
pH	8 - 8.38	8.2		
TDS	147 -226	185.8		
TSS	11 - 17	14.8		
Susp C	764 -1000	856		
DOC	265 -1090	643.3		
Total CO_2	1540 -1915	1740.8		
Cl	15 - 22	18.2		
SO_4	22 - 30.5	24.7		
Si	.39- .89	.655		
Na	14 - 16.5	14.95		
K	2.25- 2.49	2.36		
Mg	10.2- 11.3	10.65		
Ca	26.8- 30.7	28.8		
Mn	0 - .01	.0025		
Fe	.01- .21	.128		
		Station 1[1]		
NO_3-N	0 - 72	2.5	72	16.40
TDN	317 -771	349	771	433.
Susp N	25 - 92	80	25	69
TDP	1 - 24	15.0	20	16.0
Susp P	10 - 18	13.75	-	-
Chl	2.7- 5.5	4.55	-	-
Cond	270 -303	288	303	291
pH	8.2- 8.39	8.27	8.3	8.28
TDS	177 -220	194	220	199
TSS	7 - 16	10.0	7	9.4
Susp C	439 -760	713	439	658
DOC	245 -770	508	682	552
Total CO_2	1351 -2317	1743	2317	1839
Cl	15 - 22	18	19	18
SO_4	21 - 32.4	25	32	26
Si	.36- 1.1	0.7	0.38	0.65

Na	13.9- 16.9	14.8	16.9	15.
K	2.4- 2.82	2.43	2.82	2.
Mg	10.2- 13.5	11.0	13.5	11.
Ca	28.5- 34.0	30.0	34.0	30.
Mn	0 - .02	0	.02	
Fe	0 - .21	.108	.01	.

Station 1

NO_3-N	2 - 24	14.83	16.5	15.
TDN	320 -545	427.22	390.5	418.
Susp N	30 -125	75.83	36	65.
TDP	19.5- 36	24.03	25.5	24.
Susp P	8.7- 21.5	15.43	9	13.
Chl	1.1- 8.45	5.25	4.35	5.
Cond	239.5-330	256.17	309.5	269.
pH	7.8-8.3	8.17	7.9	8.
TDS	135 -221	165.83	195.5	173.
TSS	10 - 25	19.17	13	17.
Susp C	370-1055	807.28	447	717.
DOC	558.7-918	601.35	776	688.
Total CO_2	1249 -2295	1596.9	2109.5	1853.
Cl	13 - 19	17	15.5	16.
SO_4	21.5- 40	23.3	33.5	25.
Si	.18- 1.68	.76	.48	.
Na	8.95-17.2	12.3	15.8	13.
K	2.23- 4.2	2.4	3.4	2.
Mg	8.15-13.7	10.6	13.4	11.
Ca	21 - 33.4	26.1	31.3	27.
Mn	.01- .03	.021	.02	.
Fe	.075- .26	.16	.245	.

Station 2[1]

NO_3-N	58 - 75		66.5	
TDN	494 -608		551	
Susp N	57 - 58		57.5	
TDP	26 - 35		30.5	
Susp P	12		12	
Chl	-		1.0	
Cond	168 -180		174	
pH	7.7- 7.9		7.8	
TDS	146 -160		153	
TSS	6 - 10		10	
Susp C	600 -940		770	

DOC	1257 -1482		1369.5	
Total CO_2	1935 -2133		2034	
Cl	1 - 2		1.5	
SO_4	7 - 7		7	
Si	2.12- 2.3		2.21	
Na	3.3- 4.5		3.9	
K	1.8- 2.13		1.965	
Mg	8.7- 9.4		9.05	
Ca	23.5- 25.5		24.5	
Mn	-		.04	
Fe	.04- .33		.185	

Station 195

NO_3-N	11 - 26	18.5		
TDN	400 -420	410		
Susp N	80 -100	90		
TDP	21 - 22	21.5		
Susp P	13 - 22	17.5		
Chl	2.2- 7.5	4.85		
Cond	112 -117	114.5		
pH	8.1- 8.1	8.1		
TDS	80 -100	90		
TSS	20 - 20	20		
Susp C	700 -910	805		
DOC	870 -910	890		
Total CO_2	910 -1157			
Cl	1 - 1	1		
SO_4	5 - 5	5		
Si	1.74- 1.9	1.82		
Na	2.13- 2.38	2.26		
K	.90- 1.07	.985		
Mg	5.7- 5.7	5.7		
Ca	16 - 17.1	16.55		
Mn	.01- .01	.01		
Fe	.17- .35	.26		

Station 200

NO_3-N	1 -139	18.5	90	57.0
TDN	356 -481	410.5	475.5	457.8
Susp N	52 -128	87.3	61	73.0
TDP	18 - 46	27.7	36	29.0
Susp P	11 - 23	20.8	13	15.5
Chl	1.0- 6.5	3.1	2.95	3.45
Cond	119 -190	139.7	164	146
pH	7.6- 8.2	7.9	7.9	8.0

TDS	40 -140	82.8	125	105
TSS	8 - 30	20.3	19	22
Susp C	508 -940	816.7	554	727
DOC	14 -1405	715.8	1300	1065
Total CO_2	851 -1899	1242	1407.5	1252.3
Cl	1 - 6	2.23	4	3.25
SO_4	7 - 12.2	8.27	9	8
Si	1.5- 2.1	1.67	1.85	1.83
Na	2.9-10.1	3.78	7.1	5.35
K	1.09-1.9	1.46	1.495	1.41
Mg	4.3- 7.2	5.5	6.9	6.43
Ca	15.1-21.7	18.1	20.35	19.38
Mn	0 - .06	.005	.035	.025
Fe	.16- .56	.36	.38	.348

Station 2

NO_3-N	1 - 38	11.25	31	20.1
TDN	267 -610	384.8	397.5	426.4
Susp N	40 -120	74.8	49	64.13
TDP	14.5-41	19.25	32.7	24.29
Susp P	10 - 21	15.56	13	15.75
Chl	1.45-9.4	4.31	3.75	4.88
Cond	235.5-313	263.6	297.7	268.73
pH	7.9- 8.5	8.25	8.0	8.15
TDS	145 -205	168.1	183.7	167.34
TSS	5 - 20	14.8	19.5	18.63
Susp C	540 -1040	765	722	799.25
DOC	173 -941	622.5	787.3	691.58
Total CO_2	1304 -2616	1708.7	2220.3	1973
Cl	14 -21.4	16.7	16.3	16.3
SO_4	20 - 32	22.9	27.3	24.1
Si	.17- 1.68	.76	.49	.68
Na	10.8-16.1	13.3	14.8	13.3
K	2.04-3.3	2.27	2.87	2.46
Mg	8.5-13.5	10.47	13	11.4
Ca	23 - 31.5	27.1	29.8	27.3
Mn	0 - .06	.02	.04	.038
Fe	0 - .50	.115	.27	.19

Station 3

NO_3-N	8 - 31	12.0	20.7	15.25
TDN	360 -410	380	399.3	389.7
Susp N	50 -110	82	54.7	71.75
TDP	18 - 40	23	32.0	26.4

Susp P	7 - 26	20	10.3	15.2
Chl	1.1- 9.5	6.7	2.15	5.2
Cond	235 -325	248.6	295.3	266.1
pH	8.0- 8.3	8.18	8.0	8.11
TDS	150 -210	164	191.3	174.3
TSS	6 - 30	22	16.0	19.8
Susp C	548 -1140	886	655.3	799.5
DOC	599 -945	599	794.3	745.5
Total CO_2	1241 -2616	1566	2239.7	1970
Cl	15 - 17	15.8	15.3	15.6
SO_4	19 - 33	21	30.3	23.3
Si	.43- 1.71	.93	.583	.80
Na	11 - 16.4	12.1	15.2	13.3
K	2.11-3.2	2.23	2.76	2.43
Mg	8.1-13.7	10.18	13.1	11.26
Ca	25.7-33.2	26.8	31.2	28.4
Mn	0 - .06	.026	.03	.027
Fe	.07- .20	.146	.14	.144

Station 4

NO_3-N	1 -115	25.1	37.5	25.03
TDN	395 -639	552.2	470	522.4
Susp N	30 -113	65.8	79.7	64.0
TDP	28 - 93	60.6	70.5	58.0
Susp P	6.5-26.5	14.5	16.5	14.2
Chl	1.0- 5.2	2.9	1.25	2.17
Cond	194 -280	215.3	246	215.8
pH	7.1- 7.9	7.6	7.6	7.6
TDS	110 -192	135.5	170.7	146.8
TSS	10	10	10	10
Susp C	450-1420	585.9	840.3	661.8
DOC	265-1477	928.8	1244.8	1161.4
Total CO_2	1344-2584	1852.8	2142.5	1909.3
Cl	3- 7.7	6.2	6	6.68
SO_4	1.23-2.29	1.59	1.6	1.67
Na	5.5-10.2	6.37	8.58	6.60
K	1.53-2.6	1.73	2.23	1.86
Mg	6.4-10.7	8.16	9.9	8.64
Ca	26.9-31.2	28.4	30.7	28.7
Mn	0 - .18	.035	.12	.060
Fe	0 - .44	.178	.34	.221

Station 4[1]

NO_3-N	0 - 28.5	8.9	24.8	18.8
TDN	294 -470	357.4	381	384.4
Susp N	53 -150	86.2	59.0	79.6
TDP	14 - 30	20.19	25.7	23.9
Susp P	8.5-21.5	13.6	11.8	13.1
Chl	2.1-10.3	4.1	3.85	3.87
Cond	233 -330	258.3	302.2	271.6
pH	7.9- 8.36	8.2	8.0	8.1
TDS	154 -220	164.5	190	176.4
TSS	6 - 30	17.1	12.3	20.7
Susp C	550 -970	720	665.7	769.6
DOC	160 -1201	667.3	849.3	776.4
Total CO_2	1244.5-2385	1669.1	2059.8	1820.8
Cl	12 - 22	15.8	14	14.9
SO_4	19.5-40	23.5	32	25.3
Si	.41-1.72	.915	.685	.92
Na	10.2-16.4	12.7	14.8	12.7
K	2.1- 3.2	2.2	2.72	2.38
Mg	8.3-13.8	10.1	13.0	11.14
Ca	26 - 33.6	27.15	32.4	28.6
Mn	0 - .055	.01	.028	.022
Fe	0 - .245	.108	.178	.149

Station 5

NO_3-N	2 - 44	16.3	33.3	22.8
TDN	300 -480	397.2	361.7	392.1
Susp N	50 -110	74.4	58.5	69.6
TDP	12 - 31	20.4	27	22.8
Susp P	7 - 17	12.8	9.3	11.7
Chl	1.1- 5.8	3.6	3.4	3.61
Cond	206 -284	245	293	256.8
pH	8.0- 8.27	8.1	8.1	8.1
TDS	110 -197	152.9	179	159.7
TSS	6 - 20	12.3	9.7	12.1
Susp C	400 -1044	661.4	769.3	707.6
DOC	588 -1009	735	845.7	773.2
Total CO_2	1206 -2645	1634.7	2287.3	1997.4
Cl	12 - 17	14.9	15	14.9
SO_4	17 - 39	20.4	30.7	23.3
Si	.23 - 1.74	.88	.63	.752
Na	9.5-16	11.74	15.0	12.56
K	1.67-3.1	2.14	2.7	2.32
Mg	8.7-13.7	10.2	13.0	9.99
Ca	22 - 34.1	26.6	32.2	28.3
Mn	0 - .04	.025	.01	.021
Fe	.06- .19	.15	.14	.143

ble 5.10 A comparison of water quality of some Shield lakes.

	Lake Winnipeg[1]	Warren Landing[2]	Southern Indian Lake[3]	Reindeer Lake[4]	Wuskwatim Lake[5]	ELA[6]	Great Slave Lake[6]	Split Lake[7]
tal CO_2 ole/1			527		1120	-	-	1973
mg/1	13.8	36	1	0.3	1.1	1.4	0.5	16.3
4 mg/1	24	28	4	2	4.1	3	0.8	24.1
mg/1		0.8	1	2	1.4	0.5	0.3	0.68
mg/1		24	2.5	1.8	2.1	0.9	0.8	13.3
mg/1		4.8	1.1	1.1	0.99	0.4	0.4	2.46
mg/1	11.1		3.6	1.3	4.5	0.9	1.4	11.4
mg/1	30.4	31	8.5	2.5	16.2	1.6	2.8	27.3
3 µg/1			20	0	1	20	50	20.1
N µg/1			299		480	177		426
sp N µg/1			78		150			64
P µg/1			12		14	7	300	25
sp P µg/1			8.7		18.7			15.7
l a µg/1			4.3		4.5			4.8
nd µmho/cm		317	77		120	19	31	268
	8	7.5	7.8	7.2	7.9	5.6-6.7	7.2	8.1
S mg/1	164		67		90	33	28	167.3
S mg/1			10		10			18.6
sp C µg/1			673		900			799
rb mg/1	6.6	35	-	-	-			

Rybicki, 1966
Koshinsky, 1973
Cleugh, 1973
Rawson, 1959, Armstrong & Schindler, 1971
Cleugh, 1974
Armstrong & Schindler, 1971
present study

Table 5.11 Estimated mean monthly values of phosphorus and flow for Split Lake, 1973.

	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Annual
Burntwood River													
flow cfs	1080	914	800	894	5933	7715	5991	4012	3626	2801	2172	1514	3121
TDP µg/1	25	25	30	25	22	20	20	1	15	15	18	20	-
Susp P µg/1	8	10	12	13	14	15	18	21	21	15	9	6	-
Nelson River													
flow cfs	66500	64120	64890	67740	96520	109280	113150	106910	102830	95620	84020	71420	86900
TDP µg/1	24	24	25	25	21	20	20	1	15	26	25	24	-
Susp P µg/1	8	10	12	15	17	20	20	15	11	10	9	6	-

Table 5.12. Estimated phosphorus loading, Split Lake, 1973.

	Winter (Nov-Apr)		Summer (May-Oct)		Annual	
	µg/l P	Loading gm/sec	µg/l P	Loading gm/sec	µg/l P	Loading gm/sec
Burntwood River						
x̄ discharge	1,229		5,013		3,121	
TDP	23.8	0.828	15.5	2.2	19.7	1.7
Susp P	9.6	0.334	22.1	3.137	15.8	1.4
Total P	33.4	1.162	37.6	5.337	35.5	3.1
Nelson River						
x̄ discharge	69,782		104,052		86,900	
TDP	24.5	48.412	17.2	50.678	20.9	51.4
Susp P	10.0	19.760	15.5	45.669	12.8	31.2
Total P	34.5	68.172	32.7	96.247	33.6	82.6

Table 5.13. Estimated net phosphorus loading into Split Lake from the Nelson and Burntwood Rivers for pre- and post-diversion.

	mean concentration Total P μg/l	mean discharge cfs	phosphorus loading gm/sec	approximate increase
Pre-diversion				
Burntwood River	35.5	3,121	3.1	-
Nelson River	33.6	86,900	82.6	-
Total	-	90,021	85.7	-
Post-diversion				
Burntwood River	25.3*	31,170	22.3	-
Nelson River	33.6	86,900	82.6	-
Total	-	118,070	104.9	22%

* Annual mean concentration of total P in Churchill River at Opachuanau Rapid, 1972 (Cleugh 1974).

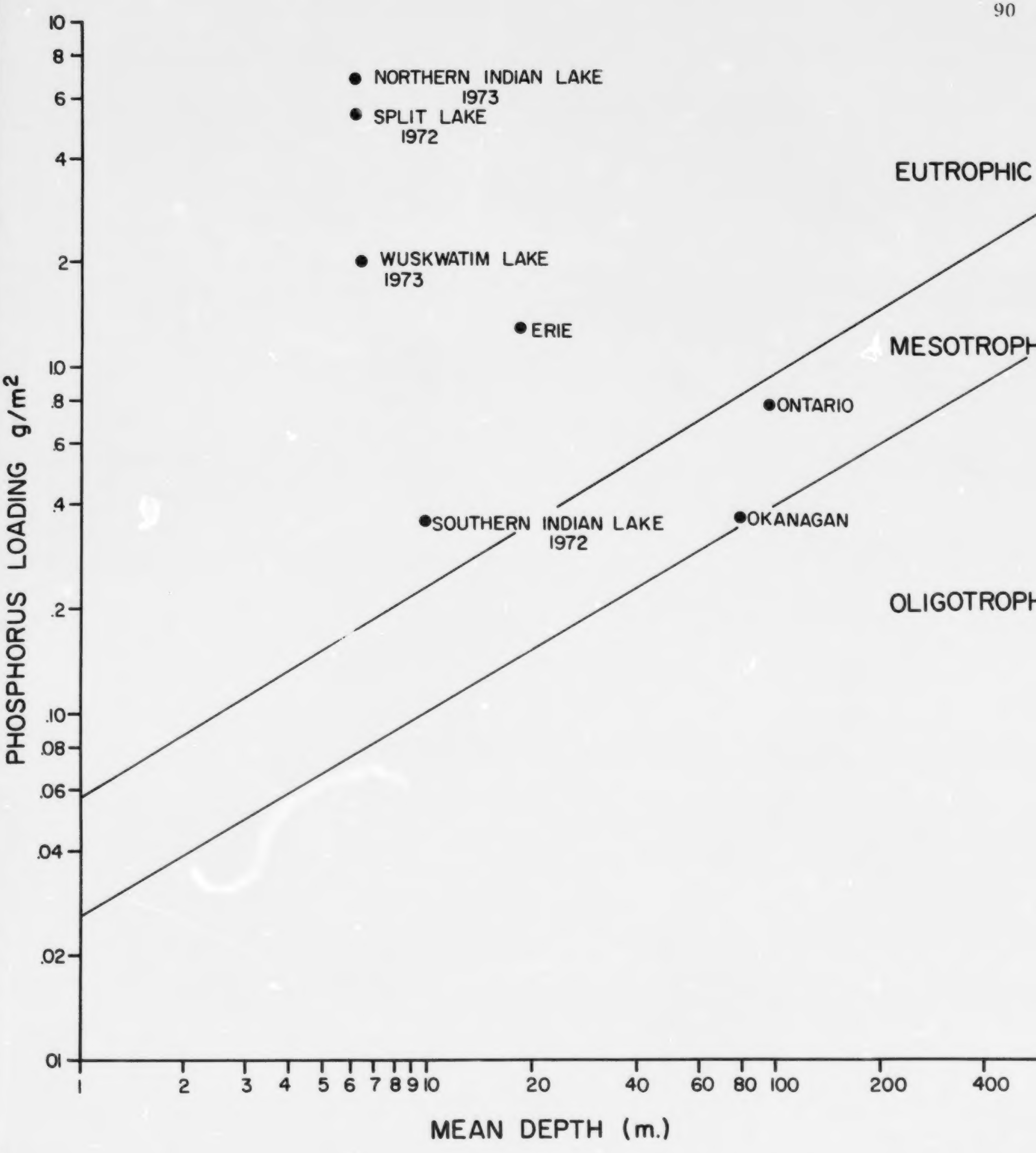

Figure 5.1. Annual total phosphorus loading of Split Lake compared to other North American lakes.

probably due to decaying organic matter, was also evident. Station 4 usually saturated or super-saturated most of the year, the lowest rec value was 71% oxygen saturation at ice-out. Moose Creek was usually saturated and oxygen levels were generally much lower. Oxygen saturat lower than 25% was common at the surface in the spring. Bottom oxyge levels were even lower. The observations were taken at the mid point the area and therefore anoxic conditions likely occur in the sha bays and close to the shoreline in the Moose Creek flooded area.

5.9. Summary:

1. The Nelson River has a mean monthly flow of 86,900 cfs, pre-div Burntwood River flow is 3,121 cfs and post-diversion flow is 31 cfs.

2. The Nelson River is isothermal with a maximum temperature of 21 the Burntwood River has a maximum temperature of 20.2°C. Moose Creek has a slight thermocline, and maximum temperature of 18.8

3. Dissolved oxygen was generally saturated on the Nelson and Burn wood Rivers. Moose Creek had much lower oxygen levels. Dissol oxygen levels were much lower after ice-out.

4. Transparency on the Nelson and Burntwood Rivers was always less than 1 meter. Moose Creek had a Secchi range of 1.5-2.6 m.

5. Twenty-six parameters were measured at twelve stations from 30 May 1972 to 26 September 1973. Results indicate the Nelson Riv

has greater concentrations of most chemical species than the Churchill River. Chemical differences were also evident between Moose Creek, and the Grass and Burntwood Rivers. Chemical parameters were relatively uniform and homogenous throughout the Nelson River with seasonal variations due to dilution by spring melt.

6. Nutrient loading (total phosphorus) was measured for the 1972 field season. Pre-diversion loading is 5.5 gms P/m^2 for Split Lake Although nutrient loading will increase due to the diversion of the Churchill River, it is unlikely that a change in the trophic status of the lake will result as the present loading rate is quite high and the turnover time will remain low after diversion.

7. Short-term impact of diversion on Split Lake will likely be increase nutrient loading, increased TSS, turbidity and sedimentation from shoreline erosion. Total suspended solids will likely increase by a factor of 3-4 in the Burntwood River with negative consequences for light penetration in the river and Split Lake.

8. Long-term impact of diversion will be increased flow and dilution of the Nelson River below Split Lake. Neither of these changes will alter the lower Nelson River substantially in the long term.

9. Impact of flooding was evident at the Moose Creek station. Lower dissolved oxygen levels from decaying vegetation, and increased nutrients from shoreline leaching were recorded.

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APPENDIX 3A

Analytical Results of Chemical Sampling

on

Opachuanau Rapids

Missi Falls

Partridge Breast Lake

Northern Indian Lake

Fidler Lake

Wood Lake

1973

Chemical parameters measured.

Total CO_2	Total inorganic carbon	µmoles/l
Cl	Chlorate	mg/l
SO_4	Sulfate	mg/l
Si	Silica	mg/l
Na	Sodium	mg/l
K	Potassium	mg/l
Mg	Magnesium	mg/l
Ca	Calcium	mg/l
Mn	Manganese	mg/l
Fe	Total iron	mg/l
NO_3-N	Nitrate	µg/l
TDN	Total dissolved nitrogen	µg/l
Susp N	Suspended nitrogen	µg/l
TDP	Total dissolved phosphorus	µg/l
Susp P	Suspended phosphorus	µg/l
Chl a	Chlorophyll a	µg/l
Cond	Conductivity	µmho/cm
pH	Hydrogen ion activity	pH units
TDS	Total dissolved solids	mg/l
TSS	Total suspended solids	mg/l
Susp C	Suspended carbon	µg/l
DOC	Dissolved organic carbon	µmole/l

Opachuanau Rapids

Date	28 February	28 March	14 June	18 July	20 August	24 September
Depth (m)	.5	.5	.5	.5	.5	.5
Total CO_2	990	-	520	520	520	265
Cl	1.5	1	1	1	1.2	1.2
SO_4	4.8	4	4	3.4	3.4	4
Si	1.4	1.6	0.96	0.94	1.16	1.25
Na	3.4	2.6	2.1	2.08	2.4	2.99
K	1.6	1.0	0.9	1.05	1.07	1.23
Mg	3.9	3.6	2.42	2.32	2.73	3.39
Ca	9.4	9.1	6.85	6.31	7.05	9.25
Mn	-	0.01	0.02	0	0.01	0
Fe	0.03	0.05	0	0.15	0.10	0.03
Nitrate	41	85	10	6	<1	1
TDN	450	323	158	-	317	227
Susp N	36	-	53	126	143	99
TDP	25	19	11	24	6	15
Susp P	5	4	8	7	13	13
Chl a	0.8	0.5	2.6	3.1	-	-
Cond	89	75	68	71	60	86
pH	7.9	7.5	7.2	7.5	7.2	8
TDS	107	78		82	50	-
TSS	10	10	2	9	6	4
Susp C	350	548		480	960	880
DOC				665	-	-

Missi Falls

Date	28 February	28 March	14 June	18 July	20 August	24 September
Depth (m)	.5	.5	.5	.5	.5	.5
Total CO_2	1080	-	1180	692	640	545
Cl	1.4	1	1	1	1.2	1.2
SO_4	5.2	5	4	3.4	3	5
Si	1.5	1.5	0.67	0.56	0.75	0.84
Na	3.2	3.3	2.62	2.29	2.27	2.14
K	1.4	1.4	1.01	0.88	0.98	1.12
Mg	4.4	4.6	3.26	3.19	3.09	2.84
Ca	10.7	11.1	9.41	8.41	8.61	8.26
Mn	0.02	-	0.03	0	0	0
Fe	0.02	0.19	0	0.02	0.07	0.05
Nitrate	41	75	4	2	1	9
TDN	425	419	266	255	261	282
Susp N	32	61	64	80	124	106
TDP	28	35	13	10	17	15
Susp P	3	4	12	3	9	15
Chl a	0.5	0.4	4.2	1.7	3.2	3.7
Cond	101	95	83	61	73	74
pH	7.6	7.8	7.7	7.8	7.9	7.8
TDS	125	86	81	54	50	-
TSS	<10	<10	5	3	3	4
Susp C	430	-	1230	480	800	980
DOC			245	800	496	689

Partridge Breast Lake

Date	14 June	20 August	24 September
Depth (m)	.5	.5	
Total CO_2	1180	720	558
Cl	1	1.2	1.5
SO_4	4	3.2	3.6
Si	7	1.3	0.84
Na	2.65	2.37	2.09
K	1.0	1.02	1.04
Mg	3.2	3.28	2.79
Ca	9.07	9.43	8.31
Mn	0.03	0	0
Fe	0	0.05	0.06
Nitrate	1	2	8
TDN	315	292	236
Susp N	74	197	135
TDP	9	13	9
Susp P	12	21	15
Chl a	-	-	2.4
Cond	85	81	74
pH	7.8	8	7.91
TDS	85	60	-
TSS	8	5	6
Susp C	1140	1080	910
DOC	260	667	592

Northern Indian Lake

	28 Feb	28 Mar	14	June	16 July	21	August	24	September
h (m)	.5	.5	.5	B*	.5	.5	B	.5	B
1 CO_2	1301	-	1330	1180	715	664	656	606	609
	1.17	1	1	1	1.2	1.2	1.2	1	1
	4.71	5	4	4	4	3.4	3.0	3.2	3.2
	1.48	1.54	0.77	0.87	0.42	0.95	0.96	0.89	0.89
	2.84	3.0	2.6	2.6	2.34	2.3	2.3	2.1	2.1
	1.22	1.16	1.01	1.02	0.88	0.99	0.98	1.02	1.07
	4.62	4.57	3.44	3.46	3.36	3.12	3.13	2.99	2.96
	12.0	10.9	10.2	9.9	8.24	8.66	9.10	8.96	9.0
	0	0.01	0.03	0.03	0.01	0	0	0	0.02
	0	0.08	0	0	0	0.07	0.04	0.06	0.08
ate	52	69	1	0	2	1	1	9	8
	379	339	278	285	306	253	230	-	398
N	40	-	74	64	80	101	101	102	110
	23	69	20	12	13	11	13	13	12
P	3	4	8	13	11	10	12	12	13
a	0.5	1.4	2.1	-	3	-	3.4	3.1	2.1
	93	90	88	89	73	78	76	78	78
	7.6	7.7	7.9	7.8	7.9	7.9	7.9	7.9	7.9
	122	85	60	51	123	60	60	76	78
	4	1	3	7	4	4	5	4	5
C	250	533	1940	800	650	570	550	650	840
	2356	927	225	213	830	505	476	494	527

Fidler Lake

	28 Feb	14 June		18 July		20 August		24 September	
(m)	.5	.5	B	.5	B	.5	B	.5	B
CO$_2$	1161	1330	1240	815	790	676	688	603	600
	1.3	1	1	1.4	-	1.2	1.2	1.0	1.4
	4.6	4	4	3.8	-	3.6	3.4	3.6	3.6
	1.4	0.77	0.78	0.43	0.41	1.04	1.11	0.92	0.92
	3.05	2.52	2.56	2.33	2.35	2.39	2.30	2.09	2.08
	1.57	1.01	0.97	0.87	0.86	0.99	0.99	1.03	1.05
	4.43	3.39	3.35	3.41	3.29	3.31	3.21	3.02	3.00
	10.8	9.9	9.8	8.95	8.74	9.75	9.24	9.09	9.39
	0	0.07	0.03	0	0	0	0	0.05	0.01
	0.05	0	0	0	0.01	0.06	0.05	0.06	0.05
te	47	0	0	1	2	1	1	8	9
	433	281	279	281	306	-	198	241	247
N	15	117	159	105	101	113	136	102	95
	26	17	11	13	17	14	13	11	-
P	3	10	25	11	11	10	13	13	15
	0.3	2.3	3.3	1.7	1.4	-	1.9	3.8	3.2
	98	88	89	82	78	83	80	78	79
	7.8	7.9	7.9	8.0	8.0	7.9	8.0	7.97	7.98
	98	66	-	-	-	60	60	-	-
	1	9	9	7	7	5	7	6	5
C	290	1020	1940	650	650	560	690	710	740
	2122	141	225	605	830	505	533	510	486

Wood Lake

e	14 June		18 July		20 August		24 September	
th (m)	.5	B	.5	B	.5	B	.5	B
al CO_2	1760	1780	1020	1070	1018	1097	959	937
	1	1	1	1	1.2	1.2	1	1
	4	3	3	3	2.6	2.8	2.8	2.8
	1.43	1.44	0.85	0.95	1.4	1.66	1.56	1.53
	1.14	1.10	1.14	1.11	1.08	1.05	1.04	1.00
	0.49	0.46	0.47	0.44	0.51	0.51	0.54	0.53
	3.94	3.68	4.19	4.16	3.92	3.93	3.93	3.88
	16.4	15.2	17.6	16.2	16.3	15.9	16.3	16.3
	0.02	0.03	0	0	0	0	0	0
	0	0	0	0.02	0.05	0.06	0.05	0.07
rate	0	1	2	-	1	1	8	8
	251	303	268	302	235	249	244	-
p N	64	64	71	52	72	63	66	71
	10	10	11	11	11	10	18	8
p P	6	7	5	4	6	6	6	6
a	2.3	2.3	3.0	2.7	3.4	3.8	3.7	2.4
d	107	110	101	97	111	112	113	112
	7.8	7.8	8	7.7	8.1	7.6	8.1	8.18
	83		81	83	80	80	80	80
	2	2	4	1	2	2	2	2
p C	330	560	410	300	600	350	640	570
	-	-	875	1025	-	-	527	673

APPENDIX 3B

Additional Locations Sampled During 1973 Study

Date	27-2-73	28-2-73	28-2-73	28-2-73	1-3-73	1-3-73	22=8-73	22-8-73
Station	Above Granville Falls	Barrington River	Old Man River	Gauer River	Little Beaver River	Little Churchill River	Little Bear River	Little Churchill River
Total CO_2 µmole/1	777	592	1301	1022	3321	2840	672	712
Cl mg/1	1.26	0.78	1.17	0.30	1.39	1.56	1.6	1.4
SO_4 mg/1	3.29	3.84	4.7	4.4	9.44	5.45	3.0	3.0
Si mg/1	1.48	0.85	1.48	1.44	2.21	2.13	0.95	1.01
Na mg/1	2.6	1.5	2.84	1.49	3.31	1.7	2.54	2.34
K mg/1	1.14	0.83	1.22	0.78	0.98	0.83	1.3	1.07
Mg mg/1	3.6	2.7	4.62	6.29	9.62	8.76	3.31	3.18
Ca mg/1	8.5	7.6	12.0	24.2	38.3	35.6	9.77	9.36
Mn mg/1	0.01	0.01	0	0.01	0	0	0	0
Fe mg/1	0.04	0.08	0	0	0	0.08	0.07	0.06
Temp °C	0	0	0	0	0	0	17.2	17.6
ice inches	-	28	24	36	46	30	0	0
Nitrate µg/1	79	56	52	18	230	110	1	1
TDN µg/1	410	435	379	418	473	315	318	189
Susp N µg/1	16	-	40	13	100	53	124	120
TDP µg/1	13	18	23	28	24	20	15	12
Susp P µg/1	4	3	2	3	6	4	17	12
Chl a µg/1	-	-	0.5	0.5	0.2	-	1.7	1.1
Cond	78	165	93	159	241	217	87	80
pH units	7.9	7.8	7.6	8.05	7.8	8.1	8.1	8.0
TDS mg/1	69	64	122	146	154	166	50	90
TSS mg/1	<10	<10	<10	<10	<10	<10	10	<10
Susp C µmole/1	336	341	280	40	1288	548	860	670
DOC µmole/1	363	529	2356	2693	223	565	869	517

APPENDIX 4A

Analytical Results of Chemical Sampling of Rat-Burntwood Lakes

1973

Chemical parameters measured.

Total CO_2	Total inorganic carbon	μmoles/l
Cl	Chlorate	mg/l
SO_4	Sulfate	mg/l
Si	Silica	mg/l
Na	Sodium	mg/l
K	Potassium	mg/l
Mg	Magnesium	mg/l
Ca	Calcium	mg/l
Mn	Manganese	mg/l
Fe	Total iron	mg/l
NO_3-N	Nitrate	μg/l
TDN	Total dissolved nitrogen	μg/l
Susp N	Suspended nitrogen	μg/l
TDP	Total dissolved phosphorus	μg/l
Susp P	Suspended phosphorus	μg/l
Chl a	Chlorophyll a	μg/l
Cond	Conductivity	μmho/cm
pH	Hydrogen ion activity	pH units
TDS	Total dissolved solids	mg/l
TSS	Total suspended solids	mg/l
Susp C	Suspended carbon	μg/l
DOC	Dissolved organic carbon	μmole/l

Issett Lake

Date	22/6/72	1/8/72	21/8/72	12/
Depth (m)	0.5	0.5	0.5	0
CO_2	-	-	-	-
Cl^-	2	1	1	
SO_4	3	4	4	8
Si	0.21	0.6	0.52	
Ca	11.7	14.1	13.3	1
Mn	.05	-	.02	-
Fe	.20	.17	.24	

Issett Lake 1972

Date	June 22	August 1	August 21	Sept 1
Depth (m)	0.5	0.5	0.5	0.
NO_3-N	5	-	-	-
TDN	290	-	370	-
Susp N	-	130	-	-
TDP	19	13	4	13
Susp P	-	-	-	-
Chl a	-	4.1	3.7	1
Cond	-	-	-	104
pH	8.1	8.0	-	8
TDS	80	110	40	100
TSS	-	<10	<10	<10
Susp C	1660	940	580	700

Karsakawigamak Lake

Date	June 14	July 18	August 20	Septemb
Depth (m)	0.5	0.5	0.5	0.5
Total CO_2	830	1970	1030	1200
Cl	1	1.2	1.2	1
SO_4	4	3.6	4	4.4
Si	1.14	.92	1.16	1.6
Na	1.52	1.85	1.98	2.4
K	.94	.94	.78	0.8
Mg	3.27	3.96	4.48	4.7
Ca	11.7	14.2	16.8	17.1
Mn	.02	0	.02	0
Fe	0.13	0.15	.21	-
Nitrate	5	5	<1	<1
TDN	286	1159	360	-
Susp N	42	164	151	73
TDP	23	19	16	19
Susp P	9	17	18	13
Chl a	1.9	3.6	3.4	2.9
Cond	88	148	112	123
pH	7.6	7.7	7.5	8
TDS	48	90	100	120
TSS	2	6	9	4
Susp C	460	770	1010	670
DOC	1600	1025	-	1258

r 24

Pemichigaman Lake

Date	June 14		July 18	July 20
Depth (m)	0.5	B*	0.5	0.5
Total CO_2	850	950	1010	1060
Cl	1	1	.8	1.2
SO_4	4	4	4	3.4
Si	1.24	1.41	1.28	1.42
Na	1.47	1.47	1.69	1.75
K	1.0	.9	1.01	.96
Mg	3.24	3.35	3.77	4.15
Ca	11.3	13.4	14.1	15.7
Mn	.03	.03	0	.01
Fe	0.14	.12	0.17	0.14

* B - indicates 1 meter off the bottom of the lake

Nitrate	3	1	2	4
TDN	222	268	1048	441
Susp N	74	64	183	231
TDP	18	20	15	11
Susp P	9	11	12	23
Chl a	-	1.6	6.2	8.8
Cond	88	94	173	108
pH	7.6	7.7	7.7	7.8
TDS	112	77	70	90
TSS	5	4	8	9
Susp C	530	520	1030	1400
DOC	1875	1340	1040	-

Rat Lake

Date	28 March		14 June		18 July		20 August		24 September
Depth (m)	0.5	B	0.5	B	0.5	B	0.5	B	0.5
Total CO_2	1192	2057	960	1430	1198	1122	960	930	1095
Cl	1	1	1	1	1.8	1.4	1.2	1.2	1
SO_4	6	6	4	4	4.8	3.6	3.4	3.4	3.8
Si	1.78	3.62	1.51	2.25	1.37	1.36	1.40	1.60	1.46
Na	2.54	3.04	1.66	2.13	2.11	1.93	1.75	1.78	1.93
K	1.24	1.49	.86	.86	1.0	1.0	.96	.97	0.90
Mg	6.93	9.28	3.79	4.69	4.04	4.04	4.15	4.17	4.15
Ca	19.0	27.9	14.0	16.5	15.6	15.4	15.7	15.9	15.4
Mn	.04	.04	.03	.02	0	0	.01	.02	0
Fe	.04	.09	.04	.04	.12	.09	.14	.07	-
Nitrate	51	-	3	-	5	2	1	1	1
TDN	480	353	278	317	984	955	396	-	310
Susp N	-	-	42	42	99	99	216	235	146
TDP	22	24	18	20	23	15	12	11	14
Susp P	3	6	9	9	19	12	19	27	15
Chl a	1.2	0.3	1.6	2.1	5.2	3.8	6.6	2.5	3.1
Cond	140	195	99	122		150	110	108	101
pH	7.5	7.3	7.8	7.2	7.8	7.7	7.8	7.7	8
TDS	31	45	57	85	88	130	110	90	90
TSS	1	2	4	3	3	2	6	10	3
Susp C	488	389	490	610	850	710	1260	1410	860
DOC	1354	1245	1125	-	1150	650	-	-	917

Mynarski Lake

Date	June 14		July 18		August 20		September 24
Depth (m)	0.5	B	0.5	B	0.5	B	0.5
Total CO_2	905	905	1060	1060	946	989	1035
Cl	1	1	1	1	1	1.2	0.6
SO_4	4	4	3.8	4	3.4	3.4	3.8
Si	0.79	0.77	.4	.4	0.93	0.96	0.53
Na	1.82	1.84	1.95	1.96	1.95	1.93	2.07
K	0.83	0.82	.91	.92	.96	.94	0.90
Mg	3.47	3.49	3.87	3.83	4.07	4.08	4.04
Ca	12.6	12.9	14.3	14.3	15.9	15.9	14.5
Mn	0.03	0.03	0	0	.01	.01	0
Fe	0	0	.05	.05	.08	.09	0.01
Nitrate	4	3	3	3	1	1	1
TDN	247	261	1161	893	369	389	374
Susp N	53	-	279	264	430	365	201
TDP	15	17	17	15	1	1	15
Susp P	8	16	20	27	33	34	21
Chl a	1.1	1.7	10.6	11.6	8.8	9.8	7.2
Cond	95	96	157	164	109	107	111
pH	7.8	7.8	8	8	7.8	8.1	8.1
TDS	73	77	62	78	80	80	80
TSS	-	2	7	9	7	9	4
Susp C	580	920	1740	1640	2510	2330	1740
DOC	1300	1075	1025	725	-	-	819

Notigi Lake

Date Depth (m)	28 March .3	3	.5	B	June 4 .5	18 July .5	B	20 August .5	24 September .5
Total CO_2	1373	1222	1277	1373	1135	1225	1212	989	1095
Cl	1	1	1	1	1	1.2	1.2	1.2	0.8
SO_4	5	6	5	5	4	3.6	3.8	3.6	3.8
Si	1.83	1.97	2.12	-	1.66	1.23	1.29	1.97	1.63
Na	2.59	2.54	2.38	2.61	2.13	2.03	2.06	1.93	2.03
K	1.09	1.08	1.06	1.15	0.9	.97	1.0	1	0.94
Mg	6.91	6.91	6.61	6.96	4.45	4.33	4.38	4.27	4.21
Ca	19.3	19.1	18.5	20.2	15.5	16.2	16.5	16.8	15.4
Mn	.03	.03	.03	-	.03	0	0	.01	0
Fe	.04	.06	.05	-	0	.1	.1	.08	0.02
Nitrate	55	82	96	-	4	3	4	<1	<1
TDN	353	353	359	408	257	822	959	545	334
Susp N	8	17	30	-	53	115	103	365	172
TDP	16	26	31	67	12	11	13	1	11
Susp P	7	5	4	-	10	13	17	29	19
Chl a	0.8	0.1	0.1	0.3	2	-	6.4	8.6	4.4
Cond	140	140	130	145	113	150	150	112	101
pH	7.5	7.4	7.3	7.1	7.8	7.9	7.8	8.2	8.1
TDS	45	127	105	-	122	79	-	90	90
TSS	1	3	1	-	4	4	7	11	6
Susp C	728	600	343	-	358	810	810	1940	1030
DOC	1463	1354	1509	1463	1165	965	920	-	852

Wapisu Lake

Date	14 June	18 July		20 August	24 September
Depth (m)	0.5	0.5	B	0.5	0.5
Total CO_2	1065	1122	1175	972	1155
Cl	1	1.4	1.2	1.2	0.8
SO_4	4	4.2	3.8	3.6	4.0
Si	1.63	1.37	1.45	1.92	1.7
Na	2.0	2.17	2.17	1.98	2.13
K	0.88	.97	.99	0.95	0.93
Mg	3.93	4.47	4.55	4.39	4.36
Ca	13.9	16.7	16.9	17.4	15.9
Mn	.03	0	0	.07	0
Fe	0	.05	.08	0.12	0.02
Nitrate	1	5	7	1	1
TDN	263	836	874	369	389
Susp N	42	248	172	280	194
TDP	20	15	14	1	19
Susp P	10	17	27	27	24
Chl a	3.3	12.1	5.0	4.3	3.3
Cond	102	150	149	113	114
pH	7.85	7.9	7.9	8.0	8.
TDS	86	81	82	100	80
TSS	4	3	10	3	6
Susp C	490	1230	1140	1220	-
DOC	1125	1040	905	-	-

Threepoint Lake

Date	28 February	18 July
Depth (m)	0.5	0.5
Total CO_2	1430	1110
Cl	1.39	1.2
SO_4	5.67	4.2
Si	2.01	1.31
Na	2.52	2.23
K	1.29	0.92
Mg	5.92	4.61
Ca	18.0	17.0
Mn	0.02	0
Fe	0.06	0.03
Nitrate	125	4
TDN	570	814
Susp N	15	172
TDP	18	20
Susp P	14	15
Chl a	0.2	6.2
Cond	134	142
pH	8.0	8.03
TDS	110	65
TSS	9	9
Susp C	618	1140
DOC	1031	1055

Wuskwatim Lake

ate	29 March		14 June		18 July		20 August		24 September
epth (m)	0.5	B	0.5	B	0.5	B	0.5	B	0.5
otal CO_2	1089	1355	990	1035	1225	1237	1065	1080	1200
	1	1	1	1	1.2	1.2	1.2	1.0	0.8
$_4$	6	6	4	4	4.4	4.0	3.8	3.8	4.4
	1.63	2.43	1.48	1.50	1.17	1.22	1.7	1.71	1.15
	2.66	2.54	1.88	1.62	2.24	2.23	2.15	2.14	2.41
	1.21	1.19	1.06	1.04	0.98	1.01	0.93	0.95	0.98
	6.92	6.93	3.83	3.83	4.62	4.54	4.73	4.78	4.98
	18.3	18.4	13.4	13.0	17.1	16.9	18.1	18.3	16.8
	0.04	0.03	0.03	0.03	0	0	0	0.02	0
	0.17	0.17	0.14	0.14	0.2	0.2	0.14	0.19	0.26
trate	61	-	2	-	4	-	1	1	1
N	378	517	239	264	816	856	393	371	403
sp N	59	27	74	95	164	138	239	189	146
P	21	41	19	22	19	20	1	1	15
sp P	15	8	13	18	20	16	20	22	21
l a	4.1	0.4	-	-	7.1	-	6.0	2.1	2.9
nd	140	130	98	99	146	143	117	119	113
	7.5	7.4	7.8	7.8	7.9	7.9	8	8	8.2
S	128	119	87	79	82	69	110	110	90
S	4	5	6	9	10	9	10	9	9
sp C	782	386	810	670	980	790	1160	1030	920
C	1454	1282	1200	1165	980	1090	-	-	-

APPENDIX 5A

Analytical Results of
Chemical Sampling
Nelson River
1972-1973

Chemical parameters measured.

Total CO_2	Total inorganic carbon	µmoles/l
Cl	Chlorate	mg/l
SO_4	Sulfate	mg/l
Si	Silica	mg/l
Na	Sodium	mg/l
K	Potassium	mg/l
Mg	Magnesium	mg/l
Ca	Calcium	mg/l
Mn	Manganese	mg/l
Fe	Total iron	mg/l
NO_3-N	Nitrate	µg/l
TDN	Total dissolved nitrogen	µg/l
Susp N	Suspended nitrogen	µg/l
TDP	Total dissolved phosphorus	µg/l
Susp P	Suspended phosphorus	µg/l
Chl a	Chlorophyll a	µg/l
Cond	Conductivity	µmho/cm
pH	Hydrogen ion activity	pH units
TDS	Total dissolved solids	mg/l
TSS	Total suspended solids	mg/l
Susp C	Suspended carbon	µg/l
DOC	Dissolved organic carbon	µmole/l
Cu	Copper	µg/l
Zn	Zinc	µg/l
Cd	Cadmium	µg/l
Pb	Turbidity	ppm

For station location see Figure 1

Date	May 30, 1972					June 22, 1972				
Station	1		2		5	1	2	3	4	5
Depth (m)	.5	3	.5	2	.5	.5	.5	.5	.5	.5
NO_3-N	2	2	3	2	2	12	17	9	5	7
TDN	470	620	460	460	300	420	420	400	460	400
Susp N	50	60	50	60	50	60	40	50	30	50
TDP	21	-	14	15	12	36	24	21	28	19
Susp P	15	20	17	18	17	14	21	25	15	14
Chl a	1.2	2.2	1.2	1.7	1.1	7.3	5.4	5.4	3.0	5.8
Cond	237	242	236	235	206	254	257	239	194	239
pH	-	-	-	-	-	8.1	8.1	8.1	7.7	8.0
TDS	140	130	140	150	120	160	160	150	110	110
TSS	20	20	20	20	10	20	20	20	<10	10
Susp C	950	1160	990	1110	1040	570	620	560	490	400
DOC	-	-	-	-	-	-	-	-	-	-
Total CO_2	-	-	-	-	-	-	-	-	-	-
Cl^-	14	14	-	14	14	19	17	16	7	15
SO_4	21	22	21	21	17	23	22	19	9	20
Si	.17	.19	.17	.17	.23	.54	.59	.56	1.28	.50
Na	12.2	12.8	11.6	11.7	9.5	13.8	13.1	12.0	5.5	11.9
K	2.16	2.30	2.06	2.02	1.67	2.27	2.25	2.11	1.57	2.18
Mg	10.2	8.5	9.9	10.0	8.7	11.1	10.8	10.3	8.1	10.0
Ca	23	19	23	23	22	27	26	27	27	26

	-	-	-	-	-	.01	.02	.02	.01	.01
Total Fe	.16	.17	.17	.17	.15	.21	.23	.20	.16	.14

Date	July 12, 1972												
Station	1		2	3	4				4^1		5	196*	
Depth (m)	.5	28	.5	.5	.5	3	5	B	.5	B	.5	sfc	sfc
NO_3-N	14	19	14	10	18	13	19	12	14	16	24	42	-
TDN	-	520	610	-	470	700	550	610	470	-	480	11400	12400
Susp N	80	90	80	100	70	80	70	60	80	100	70	6300	3600
TDP	25	-	28	32	38	40	45	58	30	30	30	4800	4800
Susp P	-	-	-	-	-	-	-	-	-	-	-	-	-
Chl a	-	-	-	-	-	-	-	-	-	-	-	-	-
Cond	243	241	240	238	202	201	199	201	236	236	236	542	537
pH	8.16	8.16	8.16	8.2	7.8	7.7	7.8	7.5	8.2	8.2	8.1	7.5	7.05
TDS	190	200	170	170	130	150	150	150	180	170	170	340	-
TSS	30	20	20	30	<10	<10	<10	<10	30	30	20	150	140
Susp C	1050	1000	910	1140	570	580	530	570	820	1100	700	-	21000
DOC	-	-	-	-	-	-	-	-	-	-	-	-	-
Total CO_2	-	-	-	-	-	-	-	-	-	-	-	-	-
Cl	16	16	16	15	7	8	6	7	14	15	14	22	24
SO_4	22	22	21	20	10	9	10	9	20	20	19	111	110
Si	1.63	1.72	1.68	1.71	2.22	2.23	2.28	2.43	1.72	1.72	1.74	5.6	5.6
Na	11.5	11.3	10.8	11.0	5.8	5.7	5.8	5.7	10.1	10.3	10.3	34.6	34.7
K	2.33	2.34	2.22	2.12	1.70	1.66	1.67	1.66	2.10	2.11	2.16	9.6	9.6
Mg	10.5	10.4	10.3	10.2	8.7	8.4	8.5	8.6	10.0	10.1	10.4	12.0	11.9

e	.11	.04	.06	.05	.06	.06	.03	.08	.06	.06	.06	.05	.08

Station 196 is near outlet of Thompson sewage

Nelson,August 1, 1972

Station	1		2	3	4				4^1		5
Depth (m)	.5	B	.5	.5	.5	3	5	B	.5	B	.5
NO_3-N	19	13	17	8	15	22	11	12	-	13	16
TDN	420	410	-	-	-	620	520	660	-	-	-
Susp N	150	100	120	110	80	80	50	50	150	-	100
TDP	20	19	17	18	58	62	62	60	19	25	23
Susp P	-	-	-	-	-	-	-	-	-	-	-
Chl a	9.6	7.3	9.4	9.5	4.3	3.3	2.4	2.5	9.6	11.0	5.8
Cond	245	246	244	235	203	204	200	202	235	231	235
pH	8.3	8.0	8.5	8.1	7.6	7.3	7.2	7.6	8.3	-	-
TDS	170	150	160	170	150	160	130	150	180	160	180
TSS	30	20	20	30	<10	<10	<10	<10	30	30	20
Susp C	1100	970	990	1140	610	760	650	550	970	-	710
DOC	-	-	-	-	-	-	-	-	-	-	-
Total CO_2	-	-	-	-	-	-	-	-	-	-	-
Cl	16	18	16	15	6	6	7	5	14	15	14
SO_4	22	22	20	20	9	10	9	11	19	20	19
Si	.56	.58	.62	.68	1.6	1.6	1.6	1.6	.68	-	.68
Na	12.5	12.6	11.8	11.8	5.7	5.7	5.6	5.6	10.9	11.3	11.3
K	2.28	2.30	2.27	2.16	1.69	1.76	1.72	1.69	2.04	2.29	2.19
Mg	8.3	8.0	8.5	8.1	6.6	6.3	6.2	6.6	8.3	-	-

Mn	.02	.03	.03	.04	.04	-	.05	.06	.03	.04	.04
Fe	.20	.16	.21	.20	.22	.28	.22	.24	.18	-	.19

Nelson, August 22, 1972

tation	1^1	1		2	3	4			4^1		5	5^1	195	200
epth (m)	.5	.5	B	.5	.5	4	B	.5	B	.5	.5	.5	.5	.5
O_3-N	20	30	17	18	17	27	30	16	17	14	28	23	11	16
DN	400	300	340	370	280	560	-	520	370	310	480	510	400	440
usp N	70	70	90	70	90	40	60	70	80	90	110	70	100	90
DP	22	16	28	10	18	62	69	61	21	20	24	22	22	18
usp P	16	15	28	19	26	11	12	13	20	23	16	19	22	22
hl a	5.1	3.3	3.4	4.0	4.2	1.6	1.9	1.6	5.7	5.2	3.5	5.1	7.5	6.5
ond	289	272	270	269	259	213	212	211	255	253	248	250	112	123
H	8.3	8.3	8.0	8.1	8.2	7.5	7.7	7.6	8.1	8.2	8.1	8.2	8.1	8.2
DS	180	170	180	160	150	110	140	140	160	170	160	160	100	100
SS	20	10	20	20	10	10	10	10	20	20	10	20	20	20
usp C	770	600	-	760	930	500	650	630	720	850	570	920	910	880
OC	575	579	709	555	599	822	988	988	599	753	741	749	910	1025
otal CO_2	1351	1307	1190	1304	1241	1329	1339	1364	1229	1260	1206	1229	910	851
l	18	19	17	17	16	7	8	8	16	15	16	16	1	1
O_4		23	23	24	20	10	11	11	25	22	19	20	5	7
i	.70	.71	.84	.81	.87	1.51	1.51	1.49	.89	.95	.88	.88	1.74	1.67
a	13.9	14.5	13.4	13.6	12.5	6.23	6.69	6.36	11.7	12.1	12.0	11.8	2.38	3.43
	2.42	2.69	2.41	2.32	2.46	1.85	1.93	1.82	2.26	2.22	2.27	2.26	.90	1.39

Fe	.18	.07	.11	.10	.14	.18	.21	.21	.11	.14	.15	.12	.17	.23

Nelson, September 12, 1972

Station	1			2	3	4			4^1		5	195	200
Depth (m)	.5	5	B	.5	.5	.5	4	B	.5	B	.5	.5	.5
NO_3-N	19	19	19	19	16	28	26	30	13	14	28	26	32
TDN	360	330	340	330	360	590	590	580	370	330	-	420	440
Susp N	30	70	-	50	60	50	50	-	50	60	60	80	80
TDP	19	21	22	21	21	67	66	67	19	17	17	21	26
Susp P	7	7	12	11	9	8	10	8	9	8	7	13	14
Chl a	4.8	7.4	3.9	6.4	7.7	3.7	2.1	2.3	4.1	2.7	2.3	2.2	1.4
Cond	285	285	285	280	272	210	208	210	272	272	268	117	133
pH	8.2	8.3	8.3	8.3	8.3	6.9	7.9	7.6	8.2	8.2	8.2	8.1	8.1
TDS	150	180	180	160	180	130	130	130	160	150	160	80	70
TSS	10	10	-	10	20	<10	<10	-	20	20	10	20	30
Susp C	700	600	-	630	660	420	550	-	570	780	560	700	920
DOC	554	581	541	541	-	1074	1289	1057	626	690	588	870	870
Total CO_2	1948	1938	1948	1900	1891	1990	1990	2045	1939	1899	1919	1157	1343
Cl	18	18	18	18	17	7	7	7	17	17	16	51	4
SO_4	27	29	28	27	26	11	11	11	24	25	24	5	7
Si	.76	.78	.83	.81	.85	1.8	1.8	1.8	.83	.82	.85	1.9	1.95
Na	14.4	14.4	14.8	14.3	13.3	5.75	5.76	5.75	13.5	13.4	13.0	2.13	3.75
K	2.54	2.48	2.67	2.44	2.30	1.76	1.74	1.75	2.33	2.30	2.32	1.07	1.26

Ca	28.7	28.4	28.1	27.5	26.4	26.8	26.7	27.7	27.3	28.0	27.7	17.1	18.8
Mn	-	-	.01	-	.01	-	.01	.02	.01	.01	.01	.01	.01
Fe	.22	.18	.25	.14	.14	.24	.22	.21	.16	.19	.18	.35	.40

Nelson, September 12, 1972 cont.

Station	1			2	3	4			4[1]		5	195	200
Depth (m)	.5	5	B	.5	.5	.5	4	B	.5	B	.5	.5	.5
Cu	5.5	-	-	27	51	4.5	-	-	33	-	9.5	5.0	-
Zn	2.0	-	-	7.1	8.5	2.6	-	-	7.3	-	1.4	3.3	-
Cd	<1	-	-	7.7	<1	<1	-	-	2	-	<1	<1	-
Pb	<2	-	-	<2	<2	2	-	-	<2	-	<2	5.0	-

Nelson, October 4, 1972

Station	1	2	3	4		4[1]		5	200
Depth (m)	.5	.5	.5	.5	B	.5	4	.5	.5
NO_3-N	24	25	21	53	58	29	28	25	41
TDN	410	-	410	330	460	420	430	360	470
Susp N	30	40	60	30	50	40	80	60	70
TDP	26	41	40	101	63	29	21	24	26
Susp P	9	10	9	6	7	9	10	9	11
Chl a	7.6	6.0	3.2	1.6	1.4	5.1	4.1	5.7	3.9
Cond	289	285	278	212	212	269	268	265	138
pH	8.0	8.1	8.0	7.7	7.7	7.9	8.1	8.0	8.0
TDS	170	170	170	120	140	160	160	160	110
TSS	20	20	20	10	10	20	20	10	30
Susp C	370	540	610	340	590	600	610	540	600
DOC	634	713	756	1195	1230	747	767	648	-
Total CO_2	1924	1965	1811	1868	1834	1721	1748	1819	1238
Cl	18	19	16	7	7	16	16	16	2
SO_4	27	25	26	11	10	24	24	23	9
Si	.55	.61	.78	1.6	1.6	.85	.87	.88	1.6
Na	14.3	13.7	13.1	6.1	5.8	13.1	13.1	13.0	4.1
K	2.51	2.37	2.27	1.85	1.86	2.20	2.26	2.24	1.09
Mg	13.1	13.5	12.6	9.1	9.1	12.1	12.4	12.2	6.6
Ca	29.2	28.9	28.0	29.8	30.5	31.1	31.3	30.1	19.9
Mn	.02	.06	.06	.08	.04	.05	.06	.02	.06
Fe	.19	.23	.18	.22	.24	.23	.26	.18	.43
Turb.	-	-	-	-	-	-	-	-	-

	Nelson, December 13, 1972						February 28, 1973
Station	2[1]	2	3	4	4[1]	5	1[1]
Depth (m)	.5	.5	.5	.5	.5	.5	.5
NO_3-N	58	30	31	55	32	31	72
TDN	608	409	387	599	-	354	771
Susp N	57	58	52	63	56	57	25
TDP	26	25	29	-	24	25	20
Susp P	12	16	15	12	14	12	-
Chl a	-	-	-	-	-	-	-
Cond	168	313	283	-	308	284	303
pH	7.9	8.1	8.0	7.8	8.1	8.2	83
TDS	160	200	210	190	190	180	220
TSS	10	19	22	10	19	13	7
Susp C	940	904	808	636	760	724	439
DOC	1257	749	682	1477	893	880	682
Total CO_2	2133	2616	2616		2576	2645	2317
Cl	1	16	15		17	17	19.3
SO_4	7	32	32		30	30	32.4
Si	2.12	.36	.43		.47	.48	0.38
Na	4.5	16.1	16.0		16.1	15.9	16.9
K	2.13	2.95	2.82		3.11	2.66	2.82
Mg	8.7	13.0	12.9		12.8	13.0	13.5
Ca	23.5	31.5	32.3		31.8	32.4	34.0
Mn	-	-	-		-	-	0.02
Fe	.04	.07	.07		.10	.10	0.01

March 25, 1973

Station	1	2^1	200	2	3	4	4^1	5
Depth (m)	.5	.5	.5	.5	.5	.5	.5	.5
Nitrate	9	75	139	38	10	1	14	44
TDN	371	494	481	386	401	416	337	371
Susp N	42	58	52		52	136	61	
TDP	25	35	46	32	27	59	28	31
Susp P	9	12	15		7	31	12	7
Chl a	1.1	1.0	2.0	1.5	1.1	1.0	3.1	1.1
Cond	330	180	190	295	325	280	330	330
pH	7.8	7.7	7.8	7.9	8.0	7.3	7.9	8.0
TDS	221	146	140	181	194	192	200	197
TSS	6	6	8		6	2	6	6
Susp C	524	600	508		548	1420	632	1044
DOC	918	1482	1300	900	945	1045	898	1009
Total CO_2	2295	1935	1577	2080	2292	2584	2385	2398
Cl	13	2	6	14	15	5	12	12
SO_4	40	7	9	25	33	15	40	39
Si	0.41	2.3	2.1	.51	.54	1.6	.51	.53
Na	17.2	3.3	10.1	14.7	16.4	10.2	16.4	16.0
K	4.2	1.8	1.9	3.3	3.2	2.6	3.2	3.1
Mg	13.7	9.4	7.2	12.5	13.7	10.7	13.8	13.7
Ca	33.4	25.5	20.8	28.9	33.2	31.2	33.6	34.1
Mn	.02	.04	.01	.02	0.0	0.18	0	0
Fe	.26	.33	.33	.5	.17	.44	.11	.15
Colour	10	45	50	15	15	50	15	15

June 13, 1973

Station	240	1^1	2	4^1	4	200
Depth (m)	.5	.5	.5	.5	.5	.5
Nitrate	2	0	-	0	4	1
TDN	366	317	267	294	442	356
Susp N	32	53	42	53	74	53
TDP	24	23	16	14	-	28
Susp P	16	10	10	10	18	21
Chl a	2.9	5.5	3.3	2.1	3.1	2.7
Cond	262	284	278	254	221	119
pH	8.2	8.2	8.2	8.2	7.1	7.8
TDS	226	217	205	154	149	92
TSS	17	10	10	8	3	24
Susp C	810	710	550	610	830	750
DOC	265	245	173	160	265	235
Total CO_2	1540	1585	1650	1440	1760	855
Cl	15	15	14	14	3	2
SO_4	22	24	24	23	14	7
Si	.39	.36	.35	.37	1.5	1.5
Na	14.1	14.9	14.3	13.8	6.4	2.9
K	2.25	2.41	2.33	2.10	1.53	1.44
Mg	10.2	10.2	9.98	9.17	7.6	4.3
Ca	27.2	28.5	28.3	25.9	28.2	15.1
Mn	0	0	0	0	0	0
Fe	.01	0	0	0	0	.31

July 16, 1973

Station	240	1^1	200	2	4^1	4
Depth (m)	.5	.5	.5	.5	.5	.5
Nitrate	<1	<1	5	<1	<1	2
TDN	413	398	448	356	346	551
Susp N	80	92	92	84	101	88
TDP	25	24	31	19	18	42
Susp P	23	18	23	20	17	10
Chl a	3.3	5.2	3.8	3.1	2.1	5.2
Cond	400	270	130	280	265	229
pH	8	8.2	8.1	8.2	8.3	7.9
TDS	147	177	85	161	157	138
TSS	17	16	15	14	13	2
Susp C	850	760	690	790	640	450
DOC	1090	770	1405	875	785	1375
Total CO_2	1810	2040	1300	1860	1920	2100
Cl	18.4	18.6	1.8	18.0	13.8	6.0
SO_4	23.4	23.8	7.6	21.8	27.8	11.2
Si	0.61	0.45	1.54	0.38	0.52	1.23
Na	14.0	14.7	3.9	13.6	13	6.3
K	2.3	2.4	1.4	2.2	2.1	1.6
Mg	10.8	11.0	5.4	10.5	10.0	8.5
Ca	26.8	28.5	16.7	27.6	27.3	28.7
Mn	0	0	0	0	0	0
Fe	.12	.07	.48	.05	.08	.08

August 21, 1973

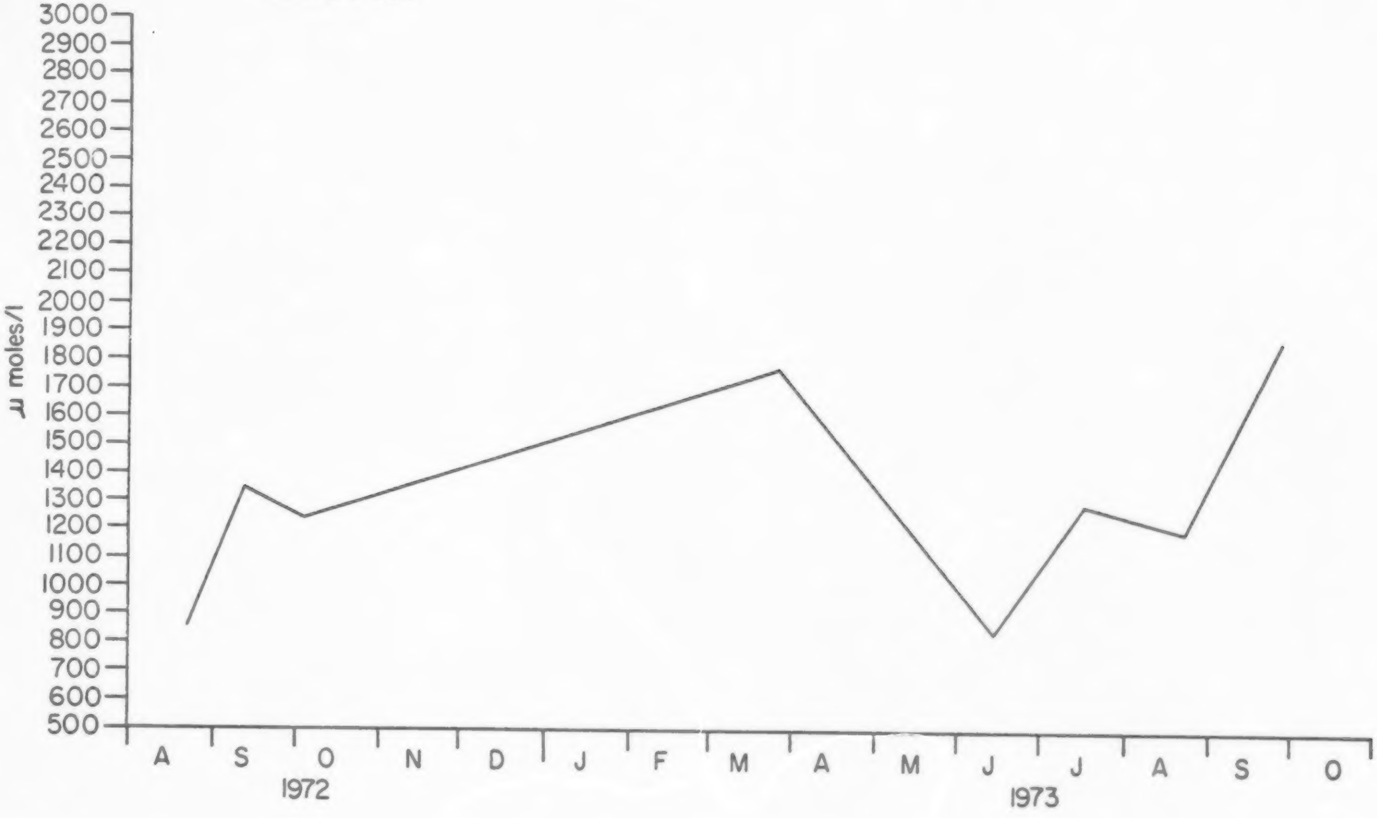
Station	240	1[1]	200	2	4[1]	4	4
Depth (m)	.5	.5	.5	.5	.5	.5	B
Nitrate	1	1	13	10	6	17	17
TDN	425	376	401	323	378	589	549
Susp N	128	86	128	97	86	113	113
TDP	1	1	31	18	21	94	92
Susp P	15	14	22	15	13	24	29
Chl a	1.6	4.8	3.3	3.6	2.8	1.6	1.3
Cond	274	294	169	286	277	242	243
pH	8.3	8.3	7.6	8.3	8.2	7.8	7.8
TDS	180	200	110	170	180	160	160
TSS	11	7	17	9	9	1	2
Susp C	764	682	940	730	570	700	700
DOC	-	-	14	650	524	1030	1020
Total CO_2	1698	1842	1204	1721	1733	1940	1964
Cl	22	22	2	21	22	5	5
SO_4	23	21	8.8	20	24	14.6	15.2
Si	0.89	1.1	1.6	1.1	1.04	1.4	1.3
Na	15.2	14.7	4.3	14.3	13.8	7.18	7.26
K	2.41	2.51	1.9	2.3	2.3	1.9	1.9
Mg	10.3	10.8	5.7	10.2	10.4	8.6	8.6
Ca	30.5	33.4	18.2	28.2	28	30	30
Mn	0.01	0	0	0	0	.07	.2

September 26, 1973

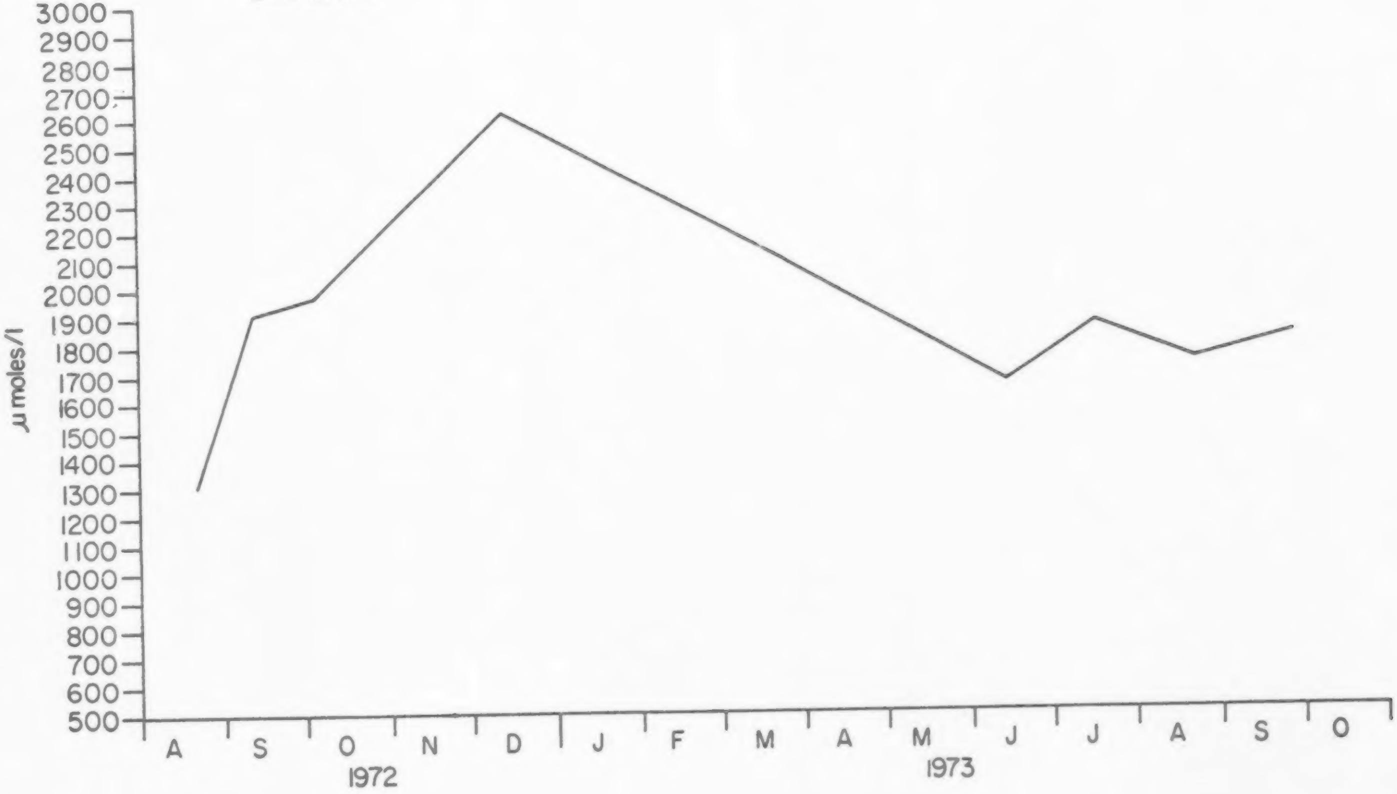
Station	240	1[1]	200	2	4	4[1]		5
Depth (m)	.5	.5	.5	.5	.5	.5	B	.5
NO_3-N	9	8	44	10	105	8	8	9
TDN	324	304	378	327	639	335	312	326
Susp N	139	88	81	110	44	73	66	81
TDP	15	12	32	19	85	-	18	18
Susp P	19	13	23	11	11	11	12	10
Chl a	2.7	2.7	1.0	2.1	3.0	-	2.7	2.8
Cond	295	303	164	266	227	283	268	283
pH	8.38	8.39	7.73	8.36	7.72	8.36	8.35	8.27
TDS	190	180	40	190	110	170	150	170
TSS	14	7	16	5	1	7	7	6
Susp C	1000	700	720	630	520	540	460	570
DOC	575	510	746	941	835	1006	1396	876
Total CO_2	1915	1899	1899	1817	1953	1709	1807	1779
Cl	17.2	16.4	2.4	15.4	7.0	15.2	15.0	15.0
SO_4	30.5	29.0	12.2	28.0	16.4	25.5	25.5	24.5
Si	0.73	0.91	1.73	1.11	1.72	1.23	1.25	1.31
Na	16.5	15.8	4.4	15.1	8.3	14.3	14.1	14.2
K	2.49	2.41	1.34	2.31	1.93	2.23	2.3	2.21
Mg	11.3	10.7	5.7	10.6	8.13	10.3	10.1	10.2
Ca	30.7	29.7	21.7	30.7	28.7	28.6	29.5	28.6
Mn	0	0	0	0	0	0	0	0.02
Fe	0.21	0.21	0.56	0.14	0.31	0.17	0.16	0.16

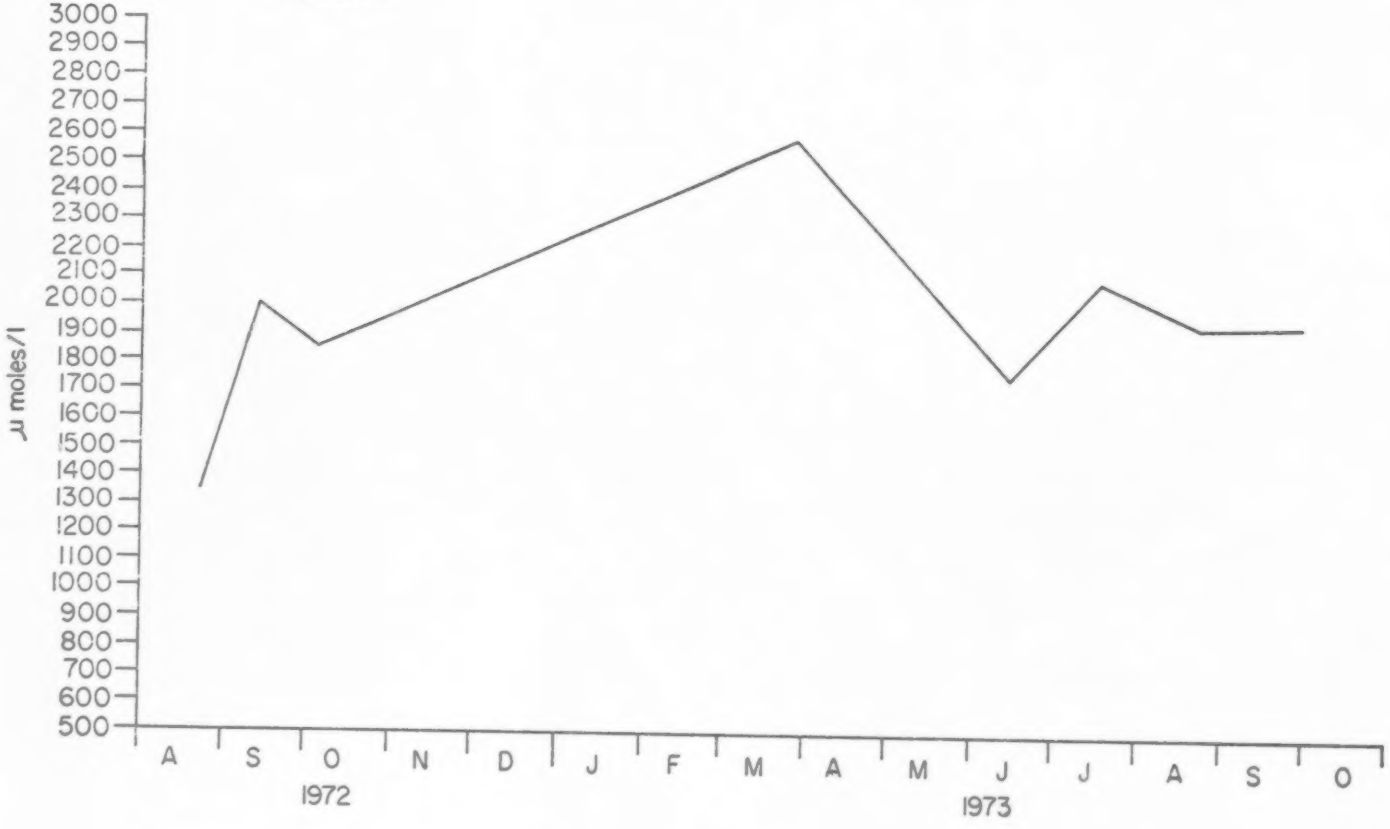
APPENDIX 5B

Graphic illustration of measured chemical parameters for stations 2 and 4[1] on the Nelson River, station 200 on the Burntwood River and station 4 on Moose Creek, during May 1972 to September 1973. For station location see Figure 1.1.


TOTAL INORGANIC CARBON
1972 - 1973
STATION 200

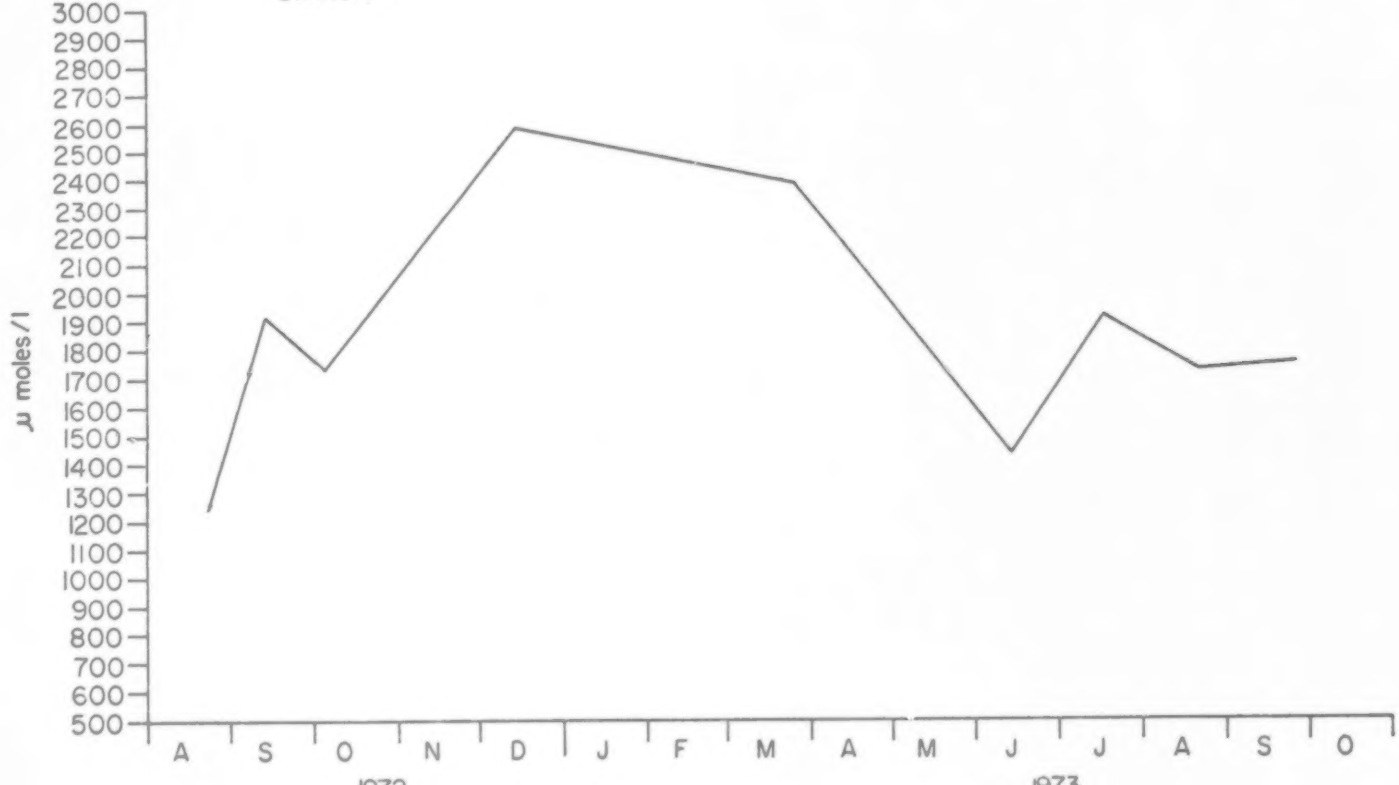
TOTAL INORGANIC CARBON
1972 - 1973
STATION 2

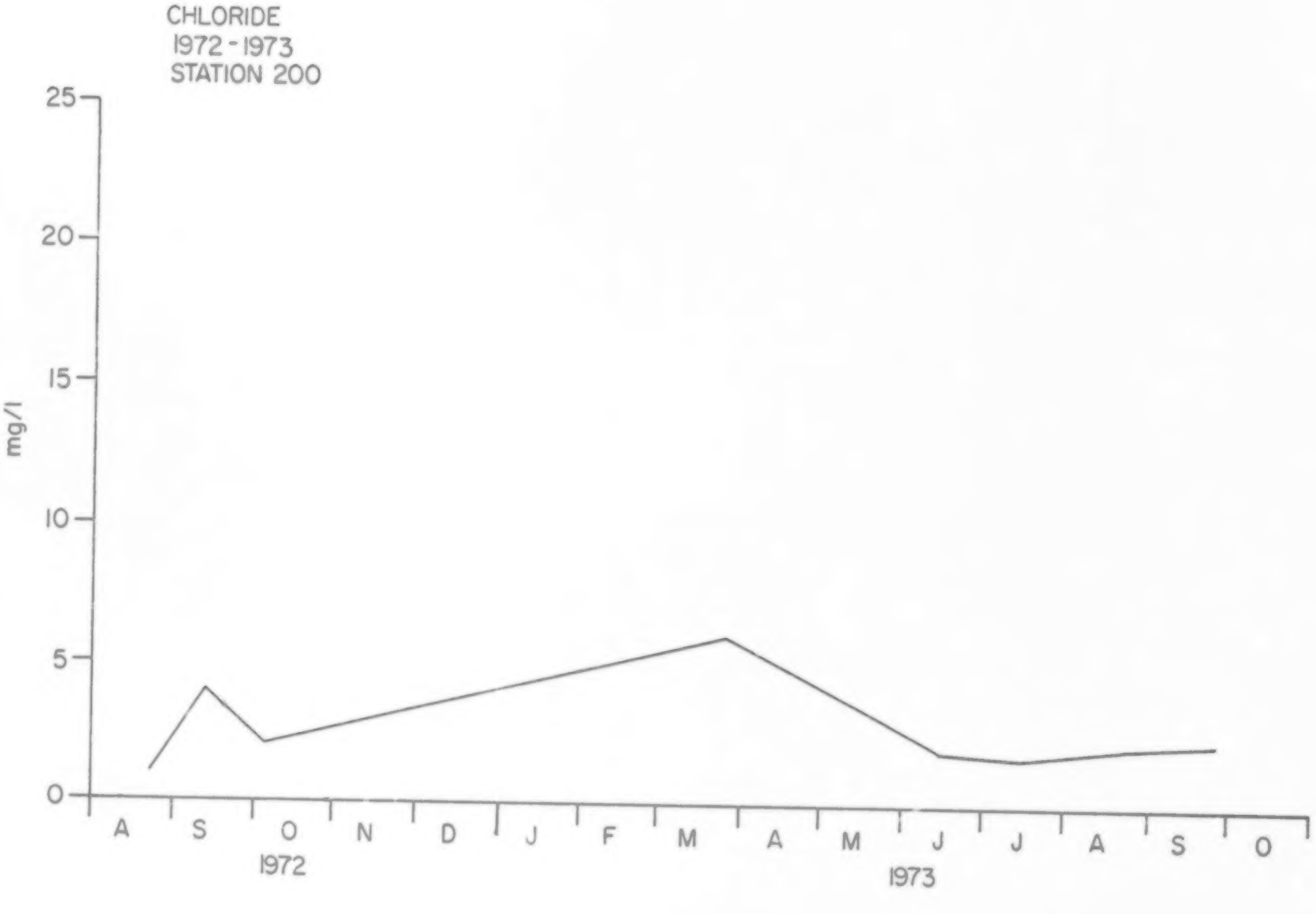




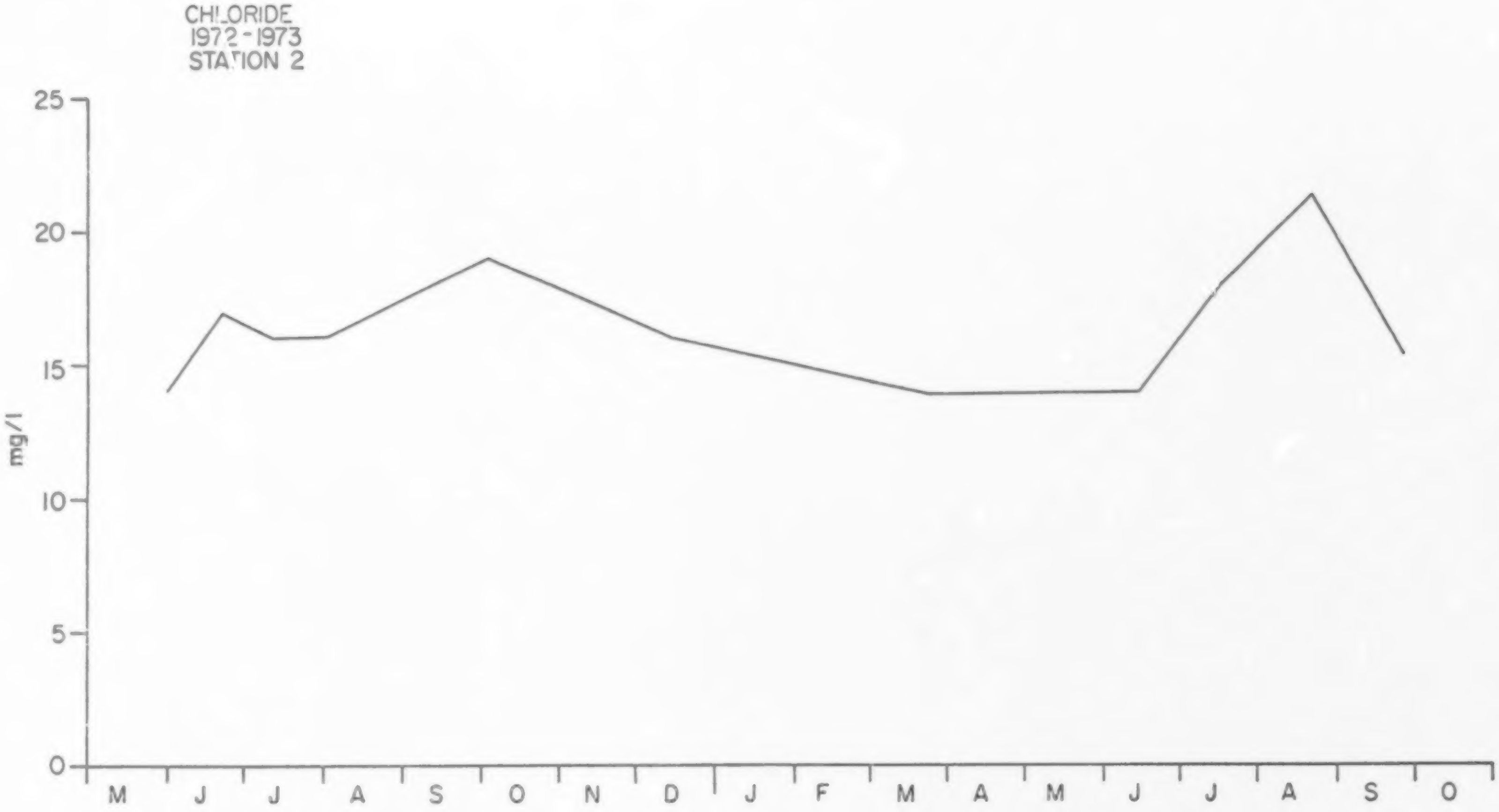
TOTAL INORGANIC CARBON
1972 - 1973
STATION 4

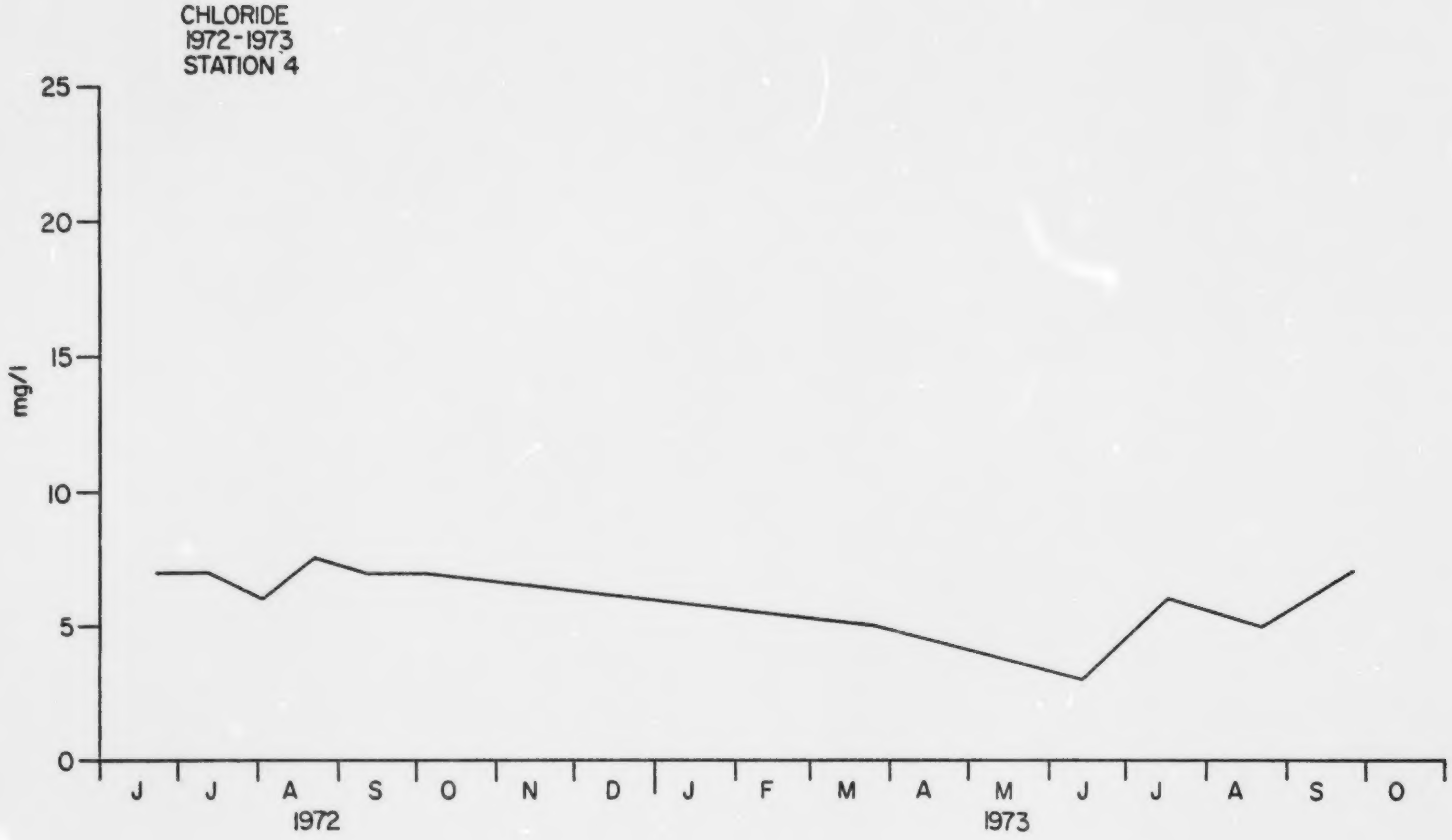
TOTAL INORGANIC CARBON
1972 - 1973
STATION 4'

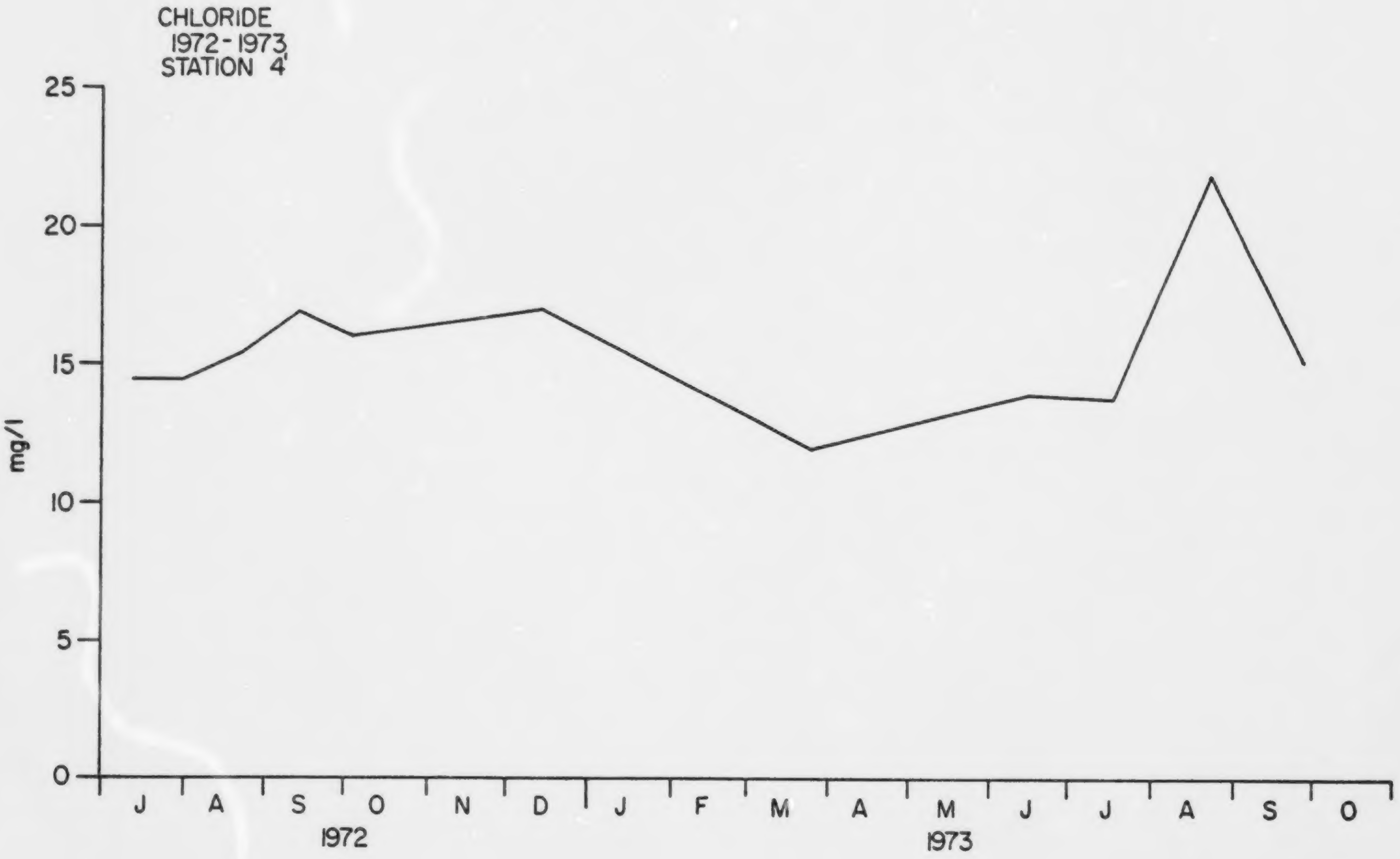


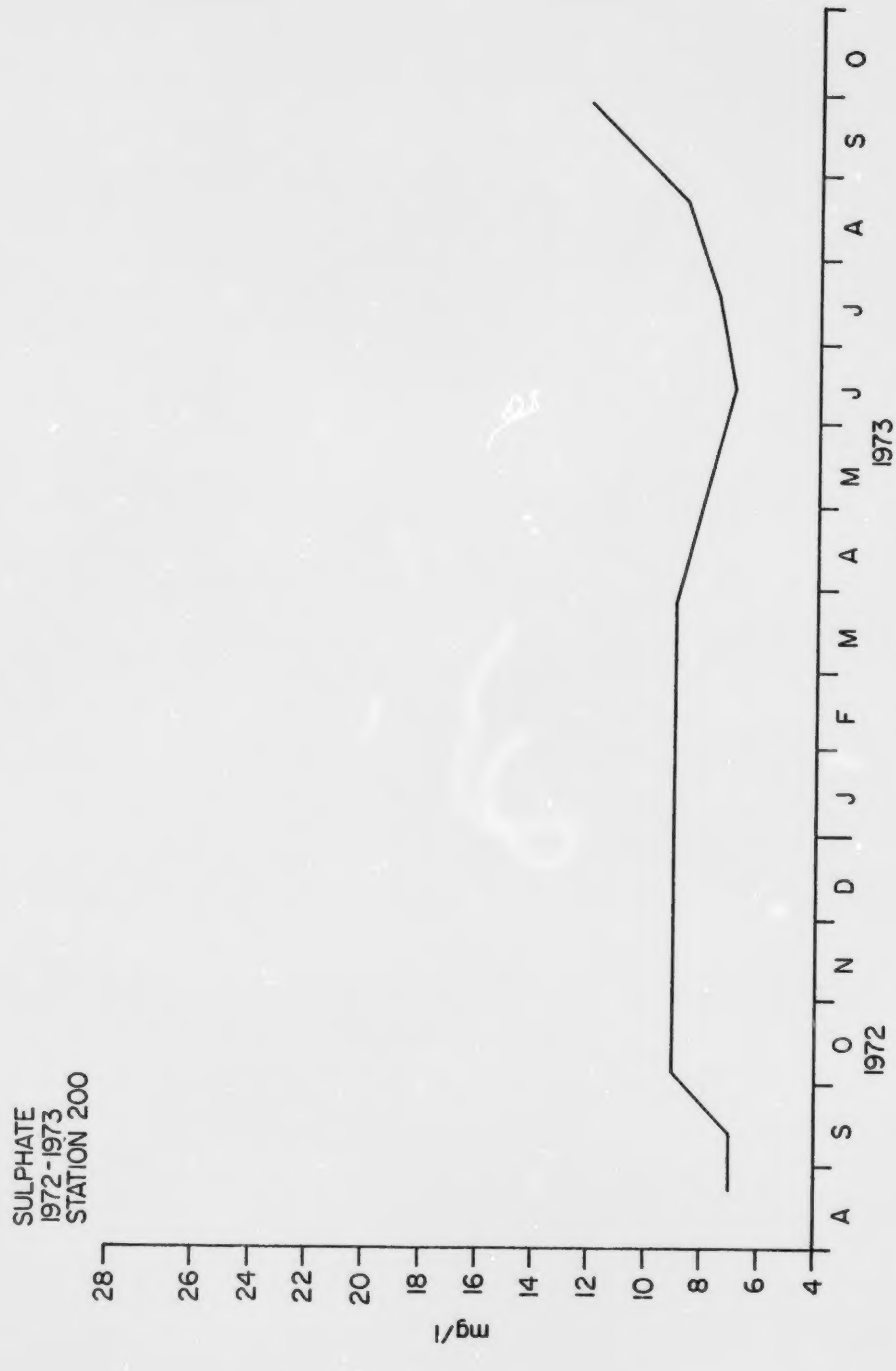


CHLORIDE
1972 - 1973
STATION 200


CHLORIDE
1972 - 1973
STATION 2


CHLORIDE
1972-1973
STATION 4
mg/l
25
20
15
10
5
0
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973


CHLORIDE
1972-1973
STATION 4'
mg/l
25
20
15
10
5
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973


SULPHATE
1972-1973
STATION 200
mg/l
28
26
24
22
20
18
16
14
12
10
8
6
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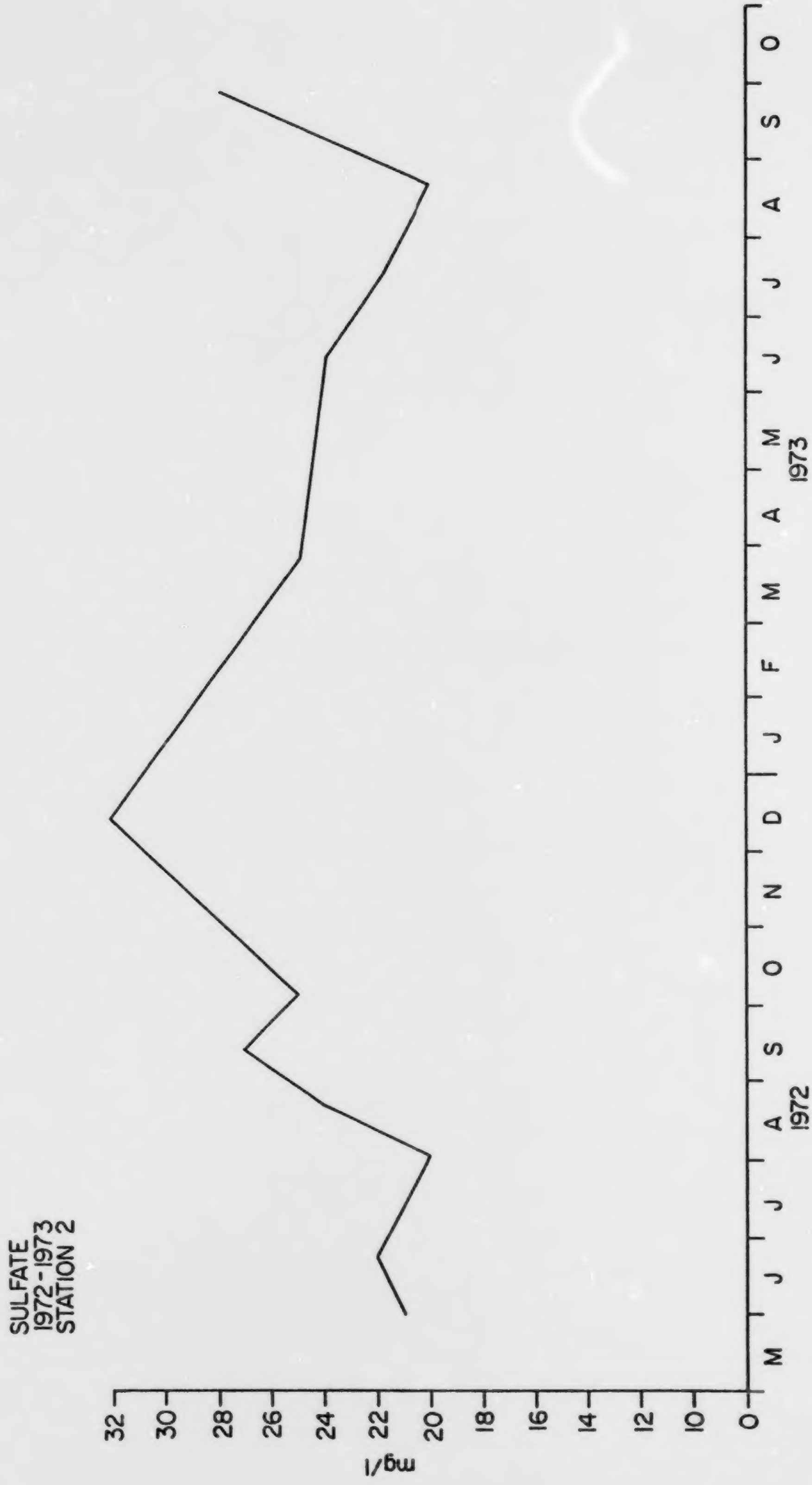
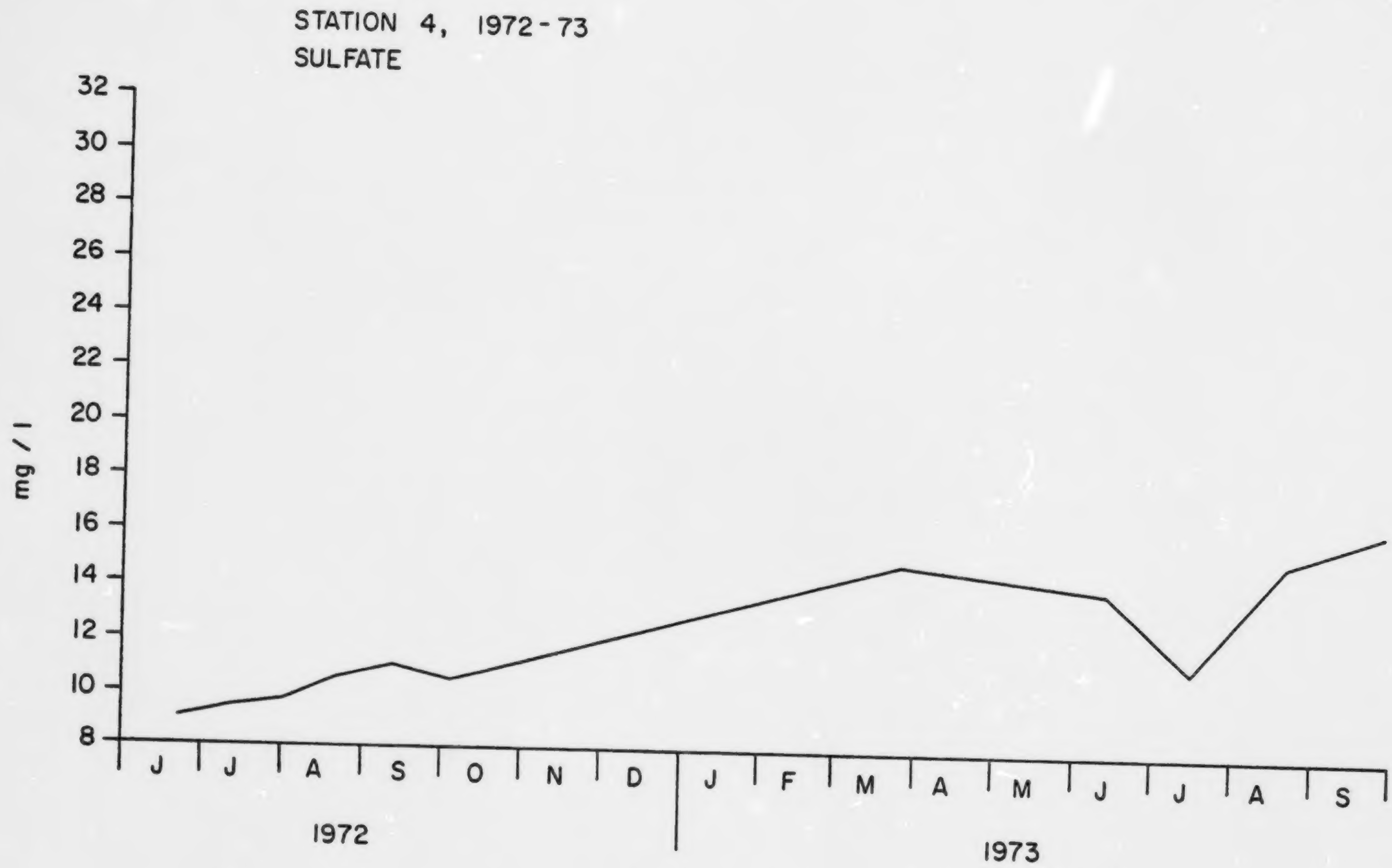
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973


SULFATE
1972-1973
STATION 2
mg/l
0
10
12
14
16
18
20
22
24
26
28
30
32
M
J
J
A
1972
S
O
N
D
J
F
M
A
M
1973
J
J
A
S
O


STATION 4, 1972-73
SULFATE
mg / l
32
30
28
26
24
22
20
18
16
14
12
10
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J
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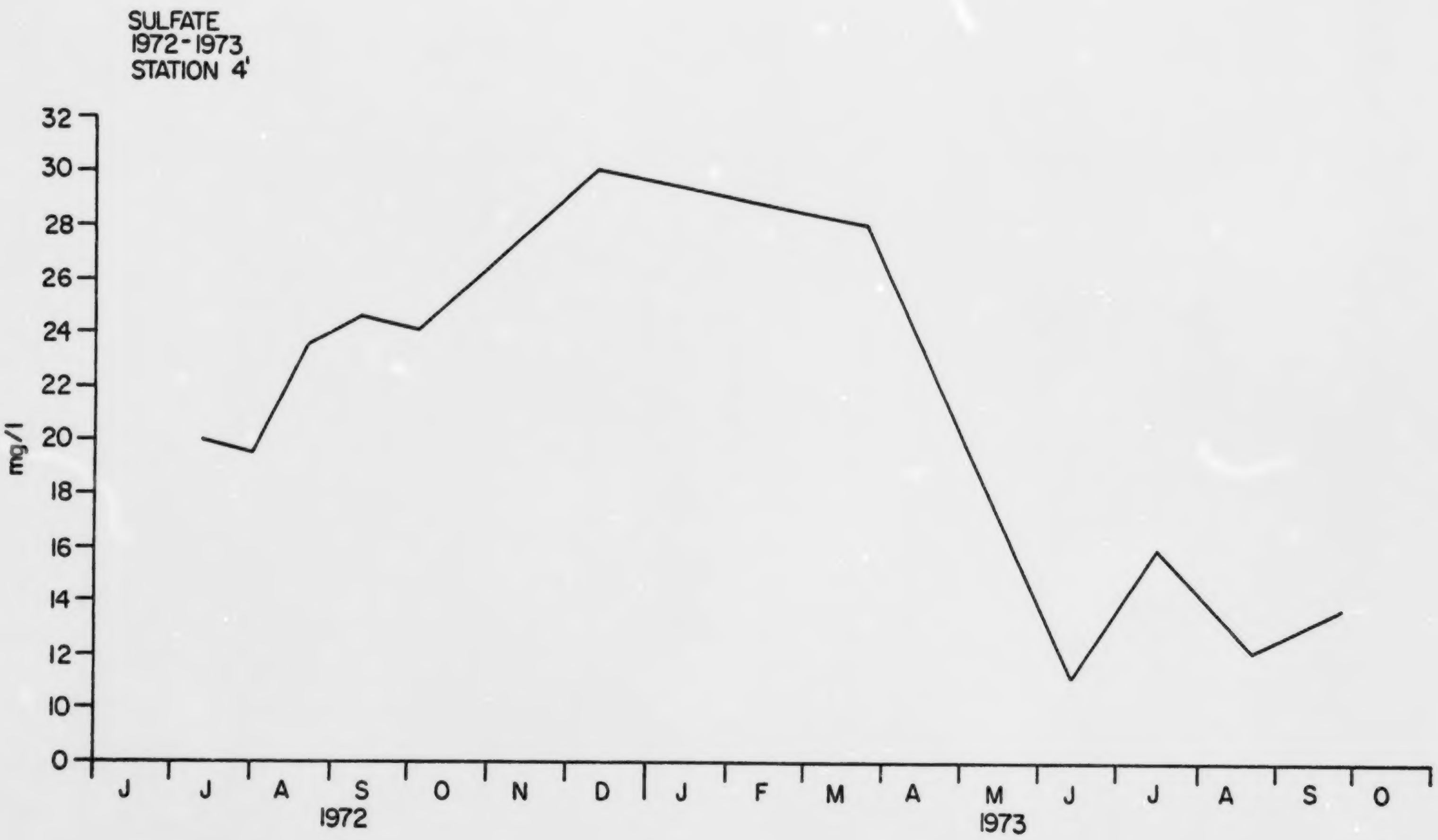
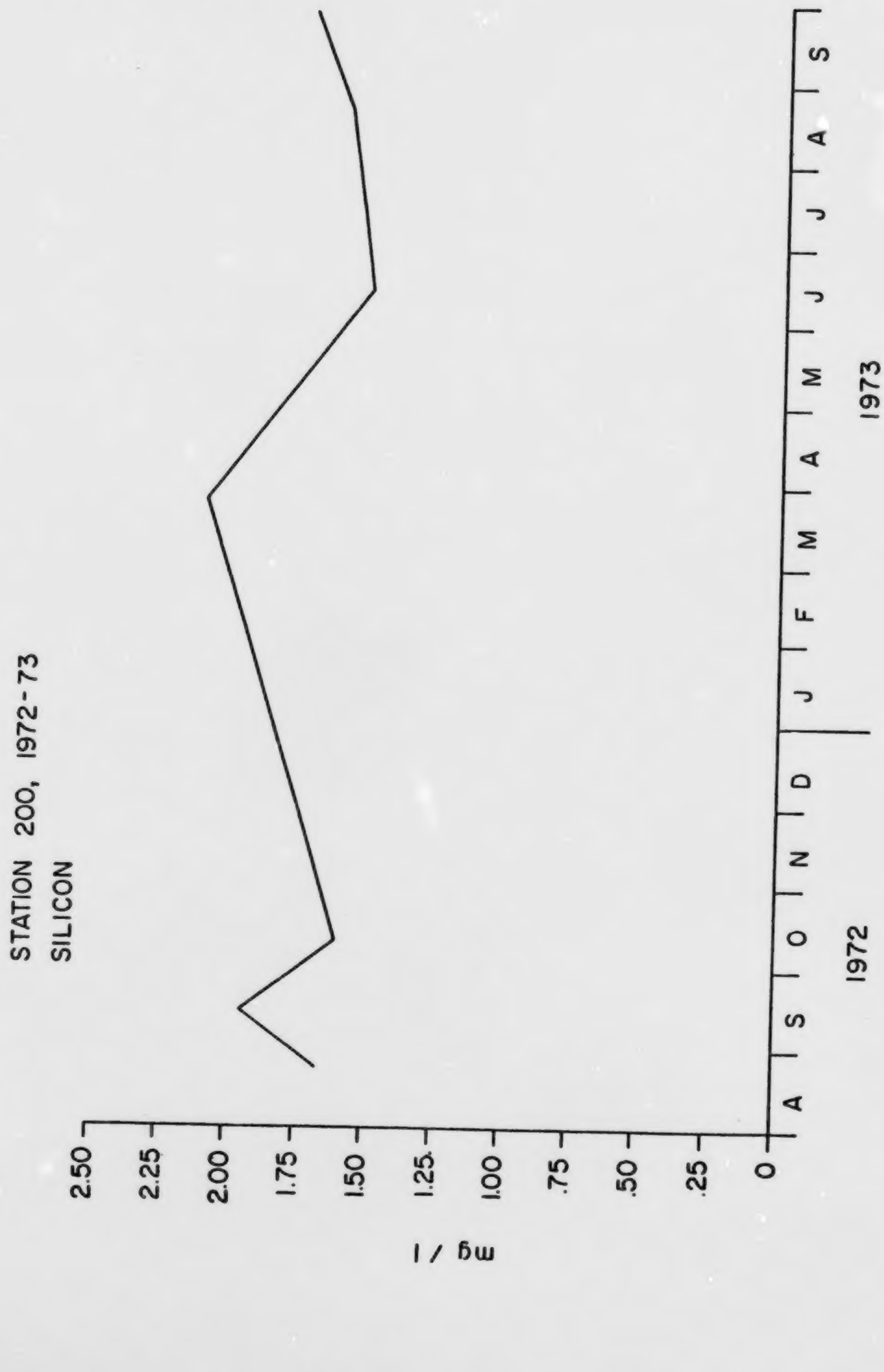
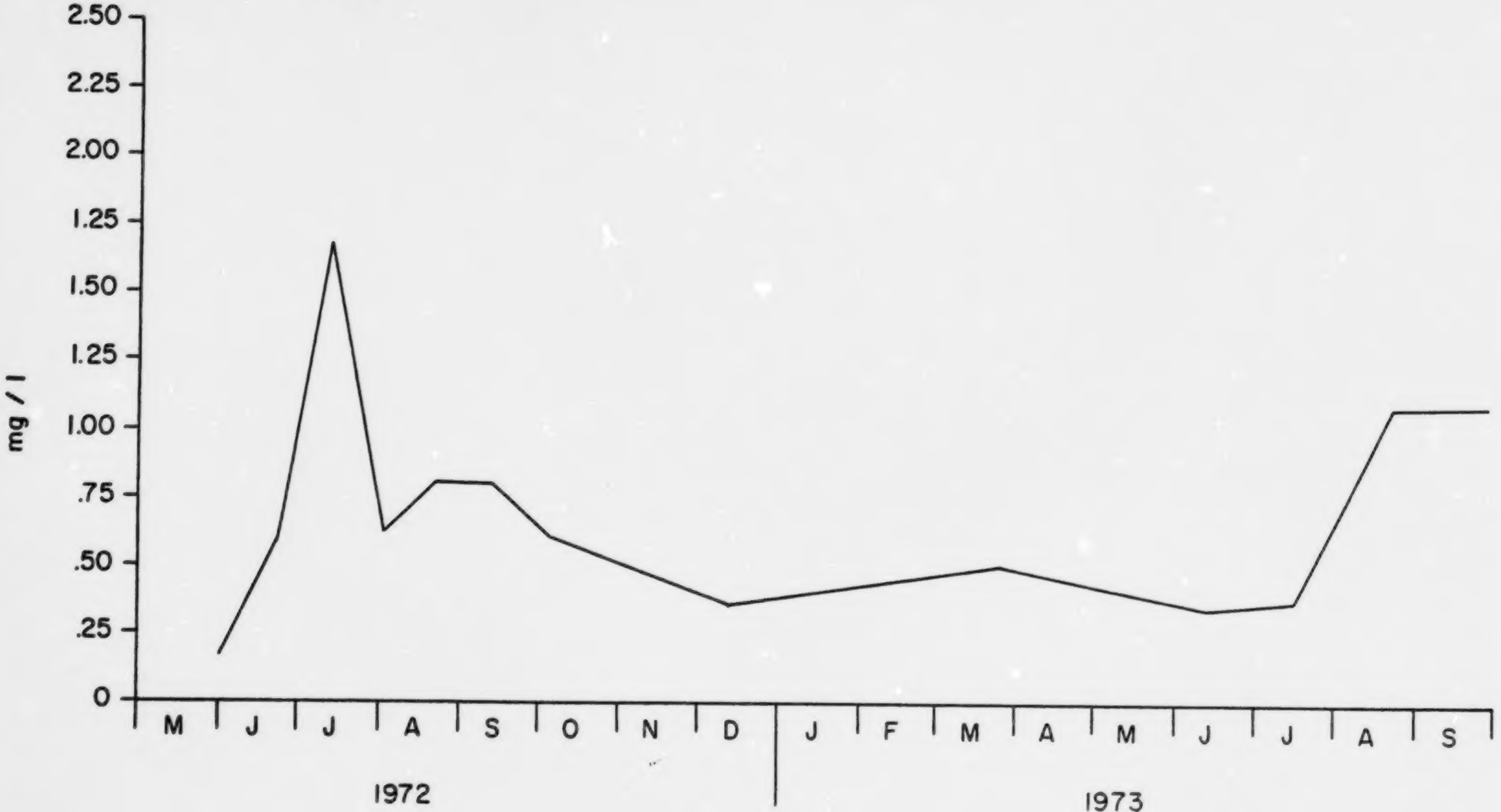
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1972
1973

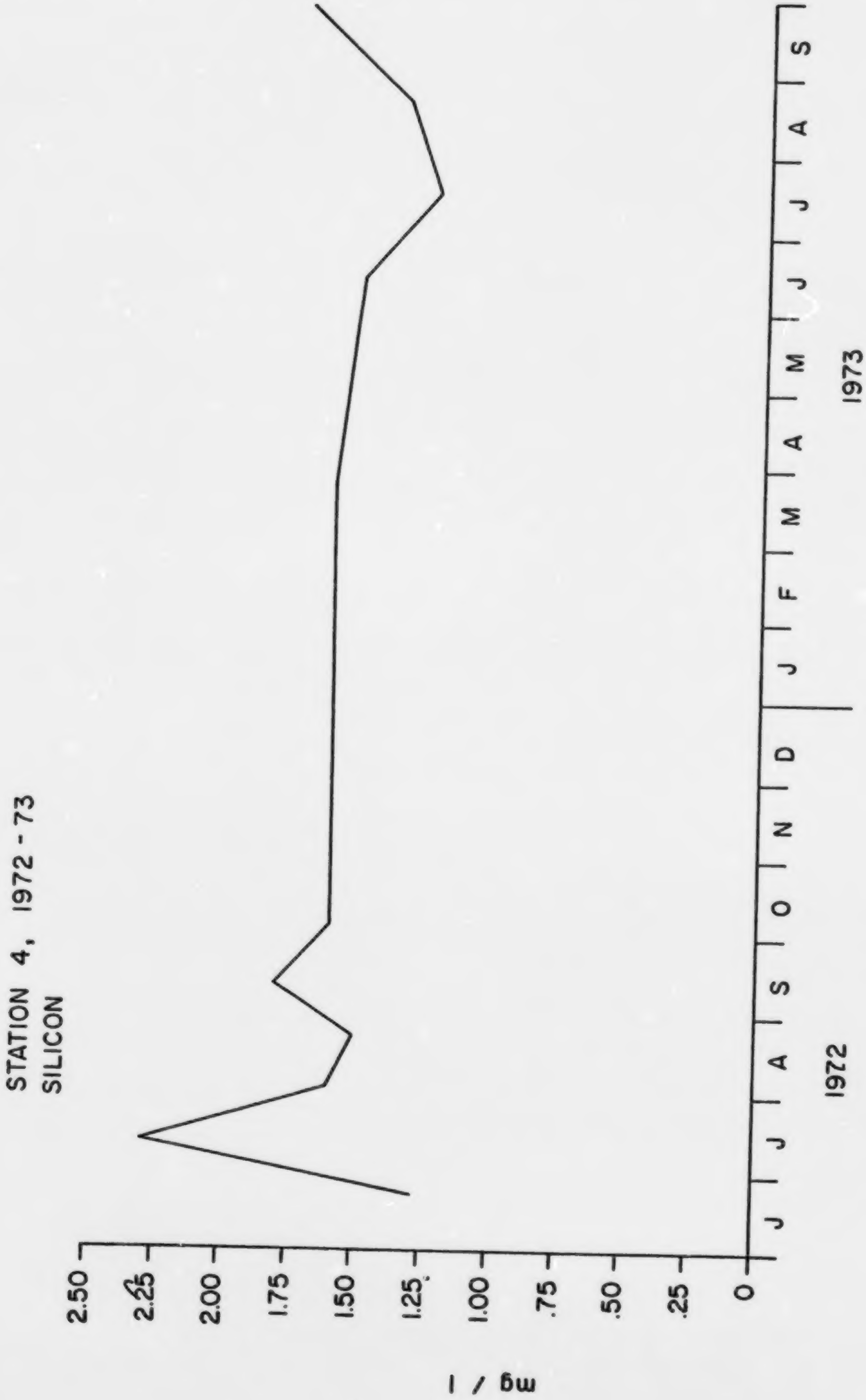

SULFATE
1972-1973
STATION 4'
mg/l
32
30
28
26
24
22
20
18
16
14
12
10
0
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973



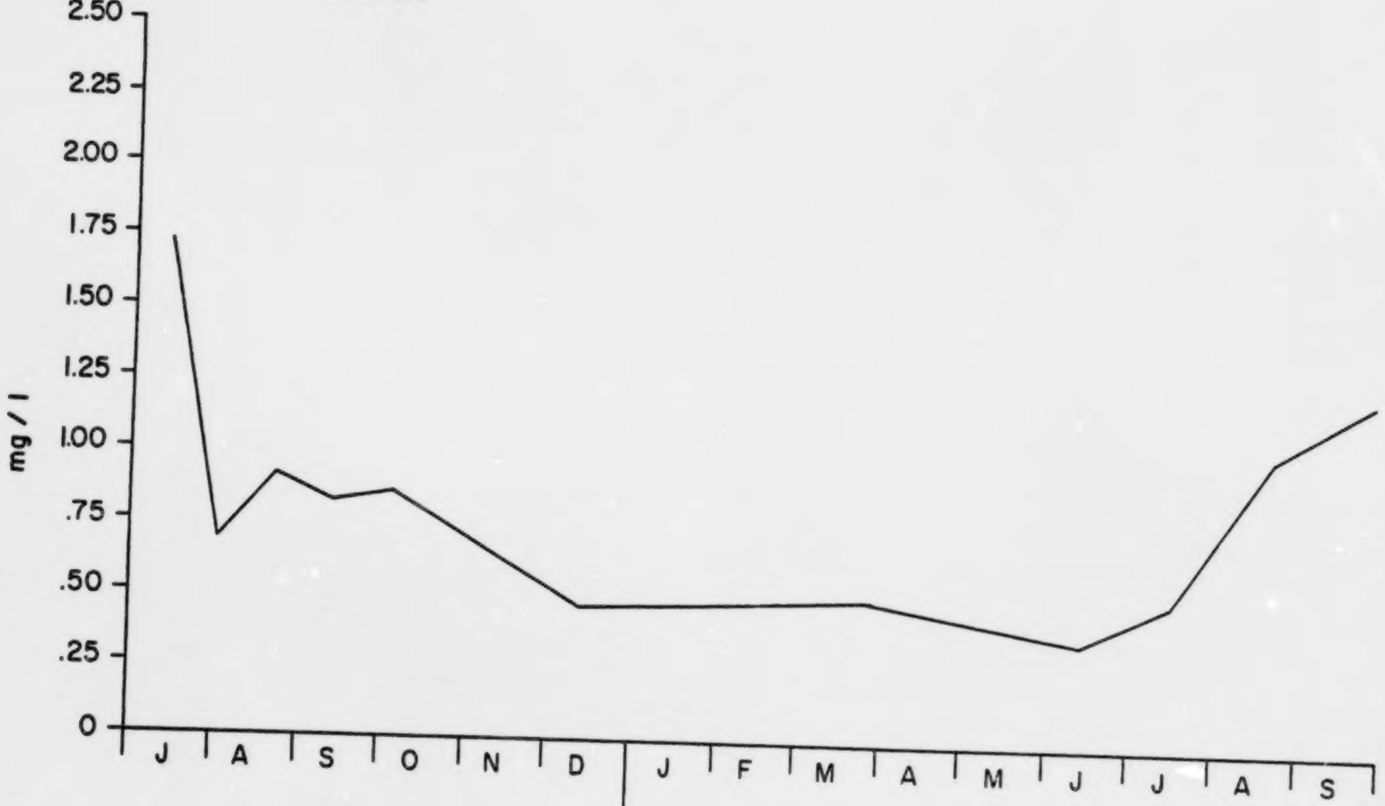
STATION 200, 1972-73
SILICON

STATION 2, 1972-1973
SILICON

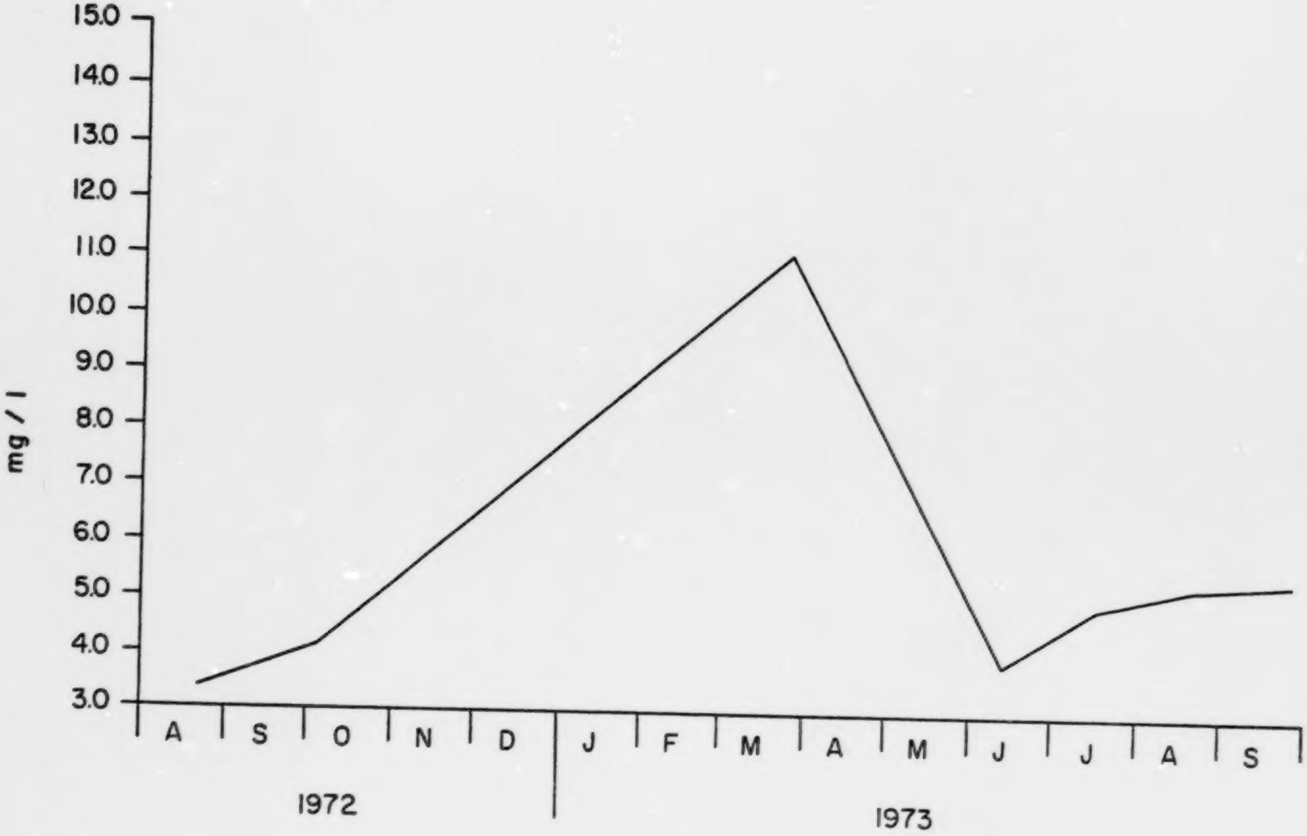


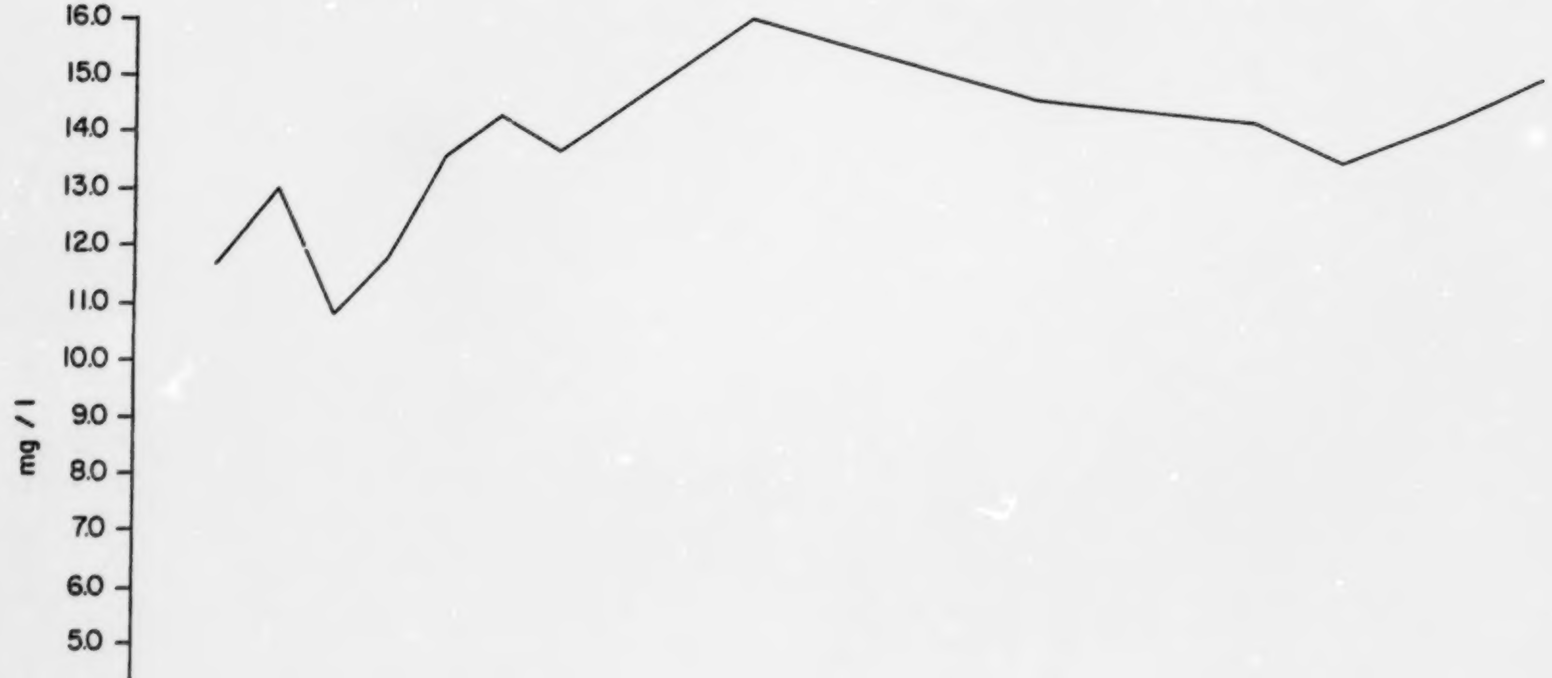

STATION 4, 1972 - 73
SILICON
mg / l
0
.25
.50
.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1972
1973

STATION 4', 1972 - 1973
SILICON

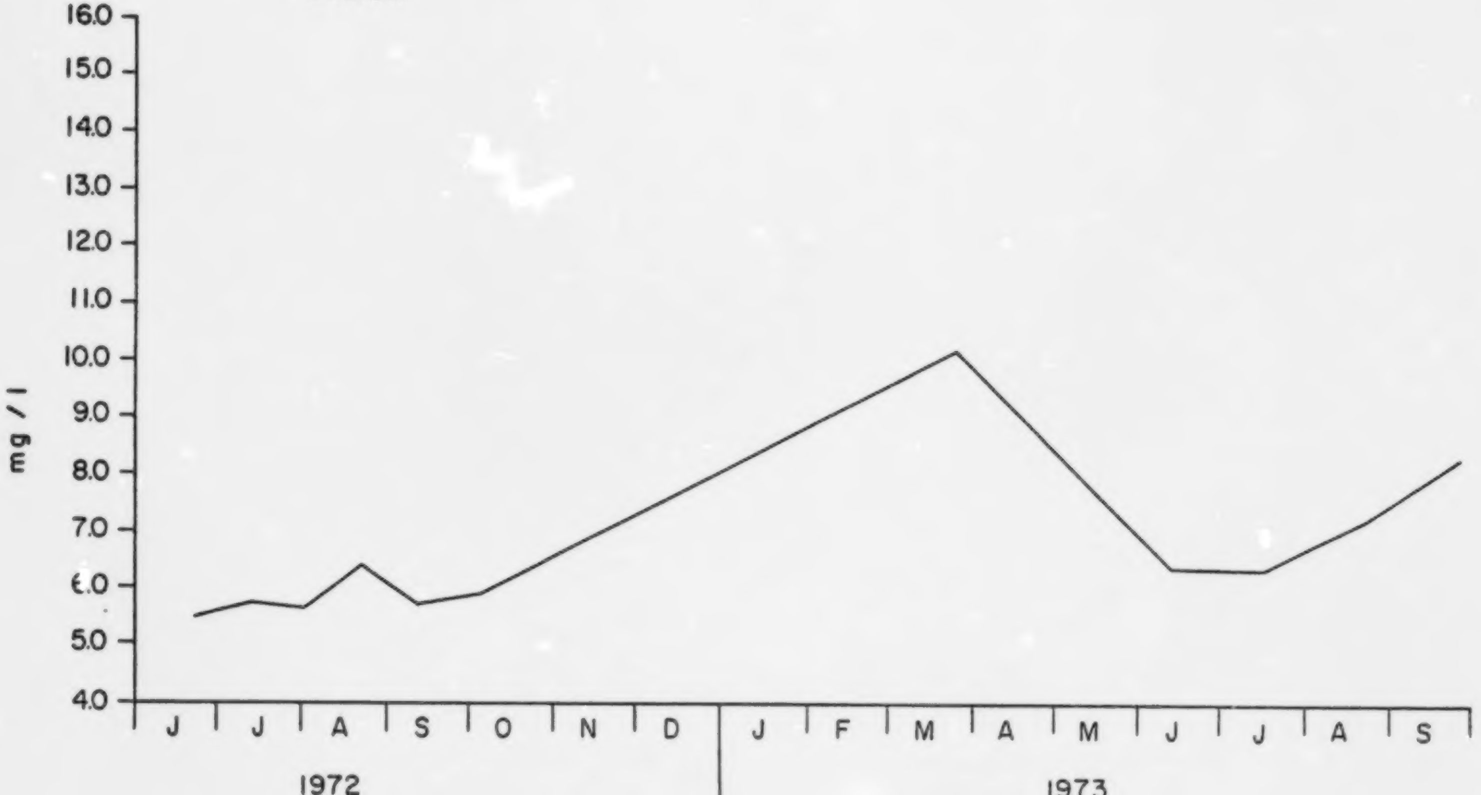


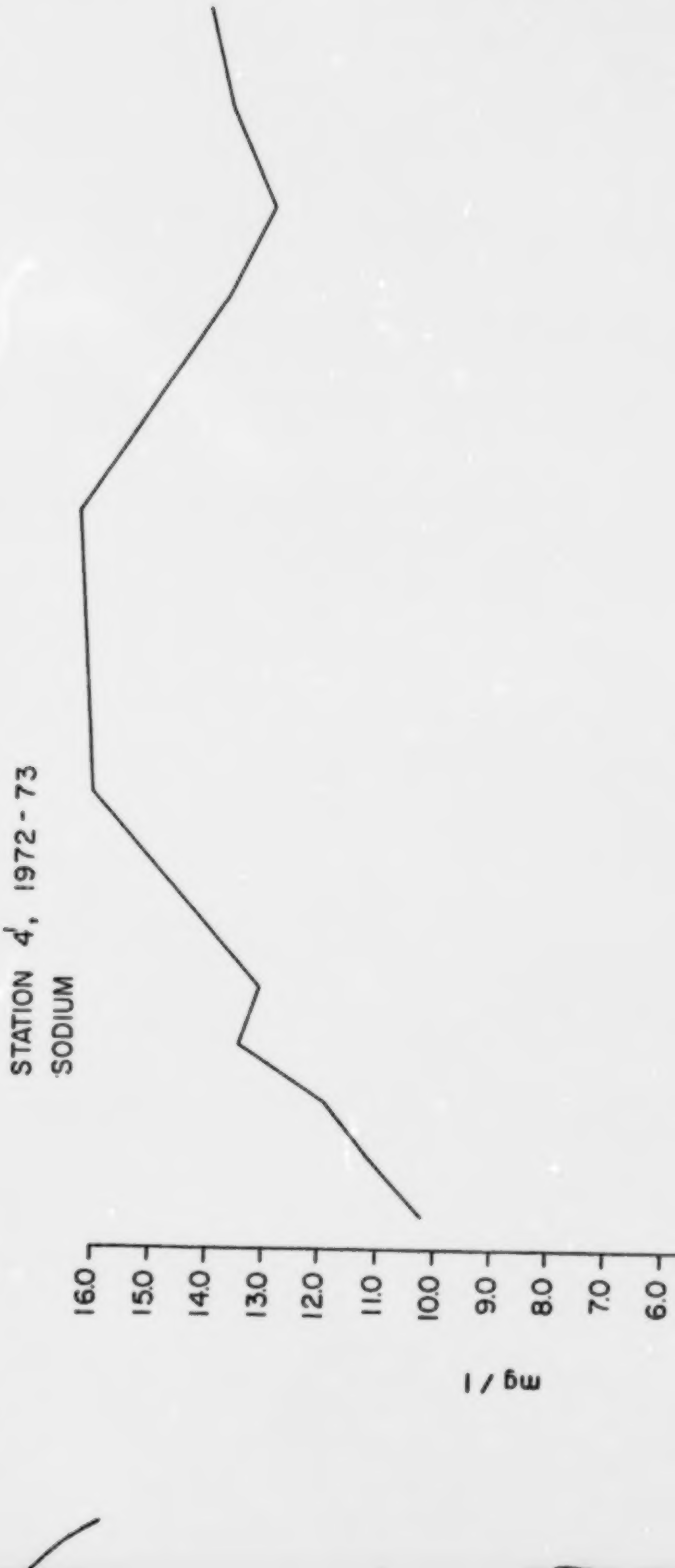
STATION 200, 1972-1973
SODIUM

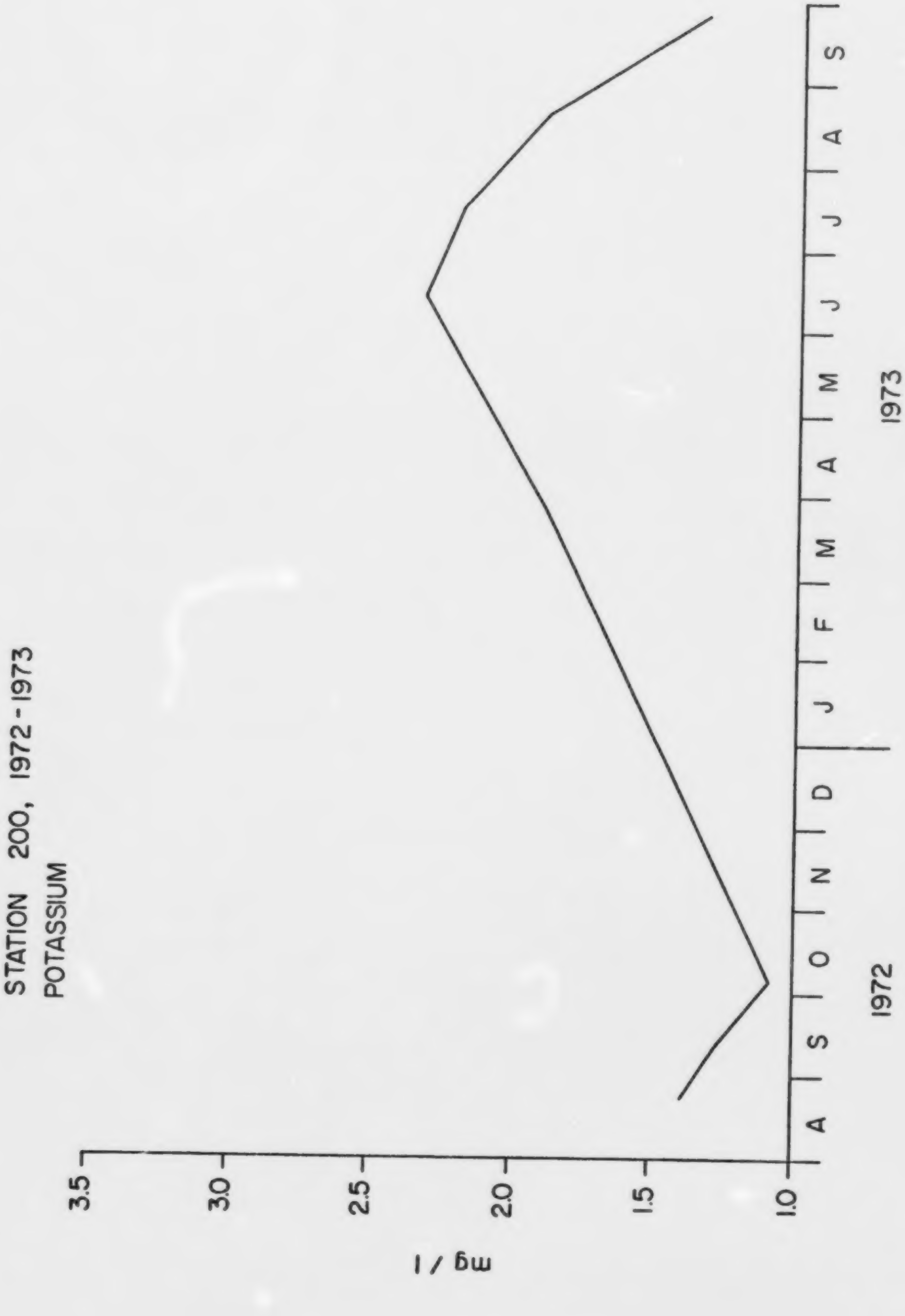



STATION 2, 1972-73
SODIUM

STATION 4, 1972-1973
SODIUM

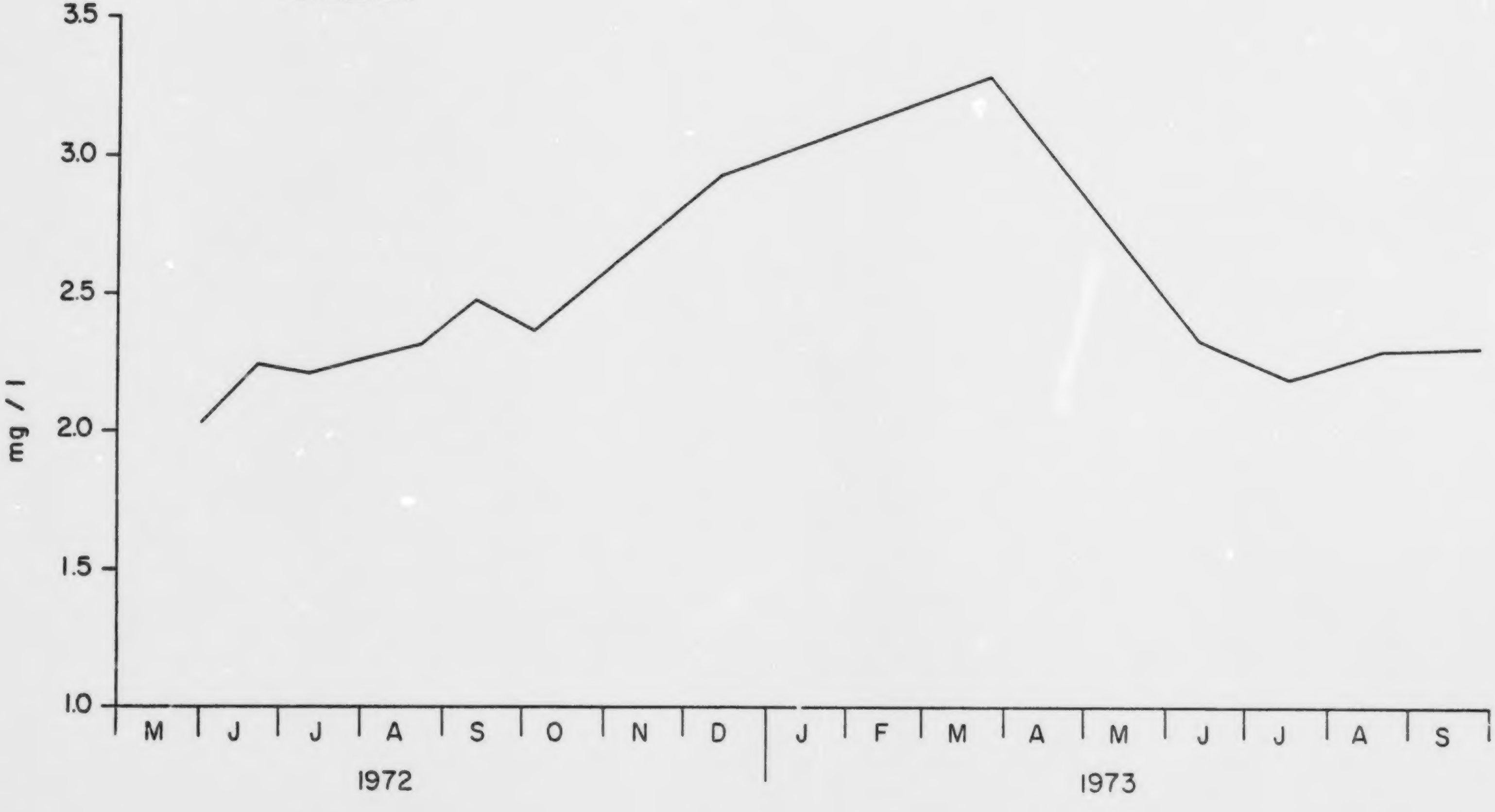


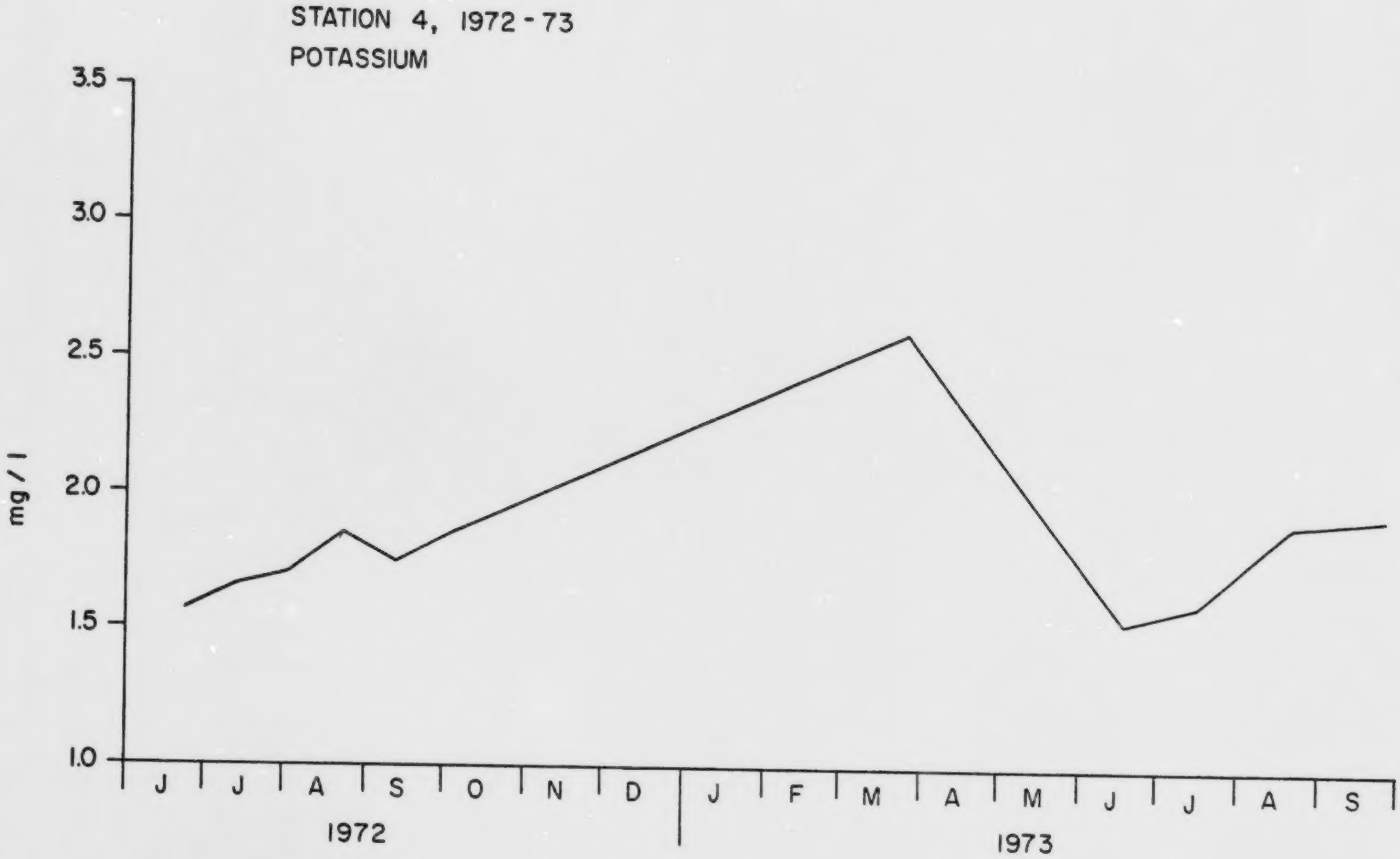

STATION 4, 1972 - 73
SODIUM
16.0
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
mg / l

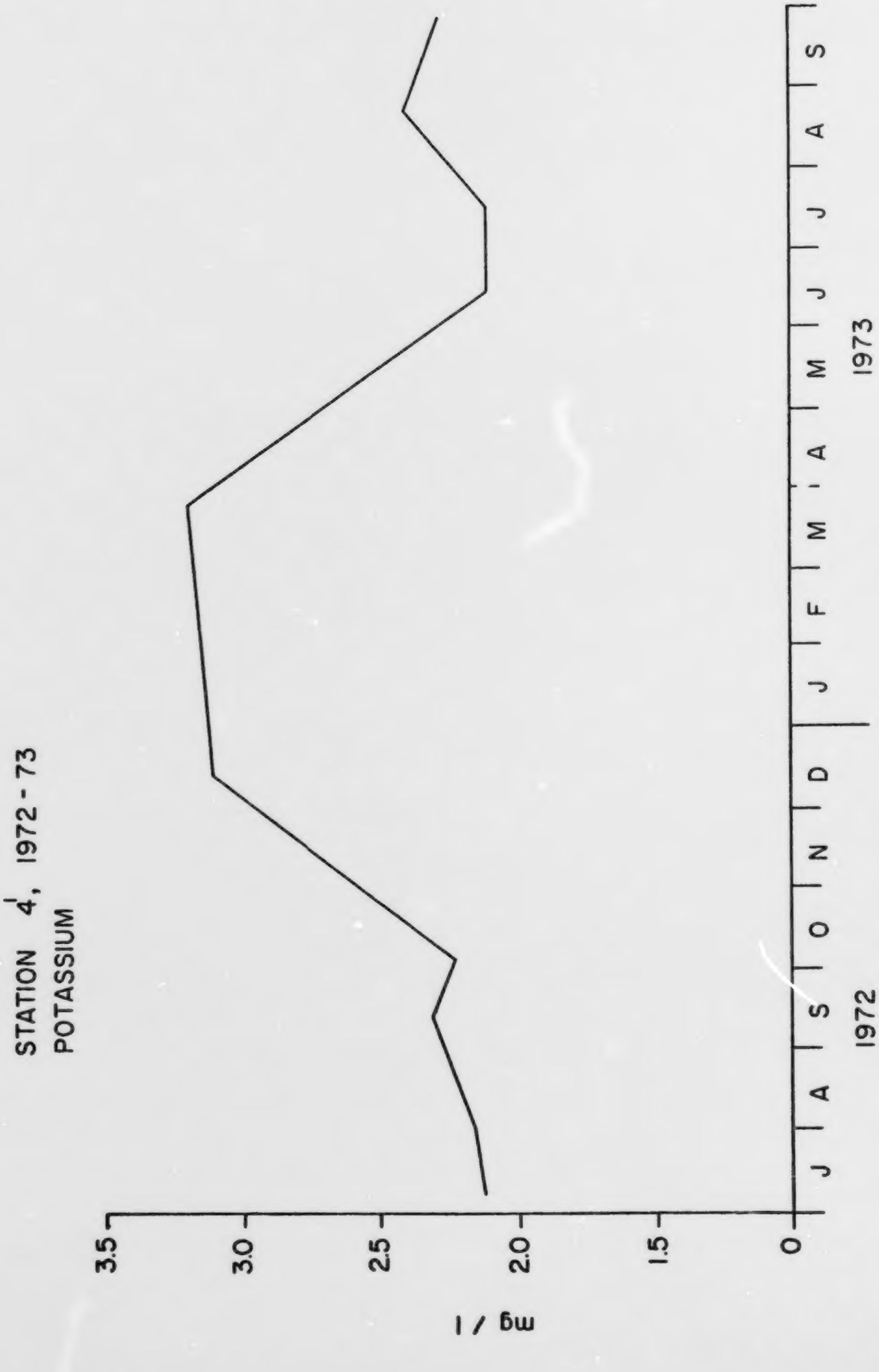


STATION 200, 1972-1973
POTASSIUM

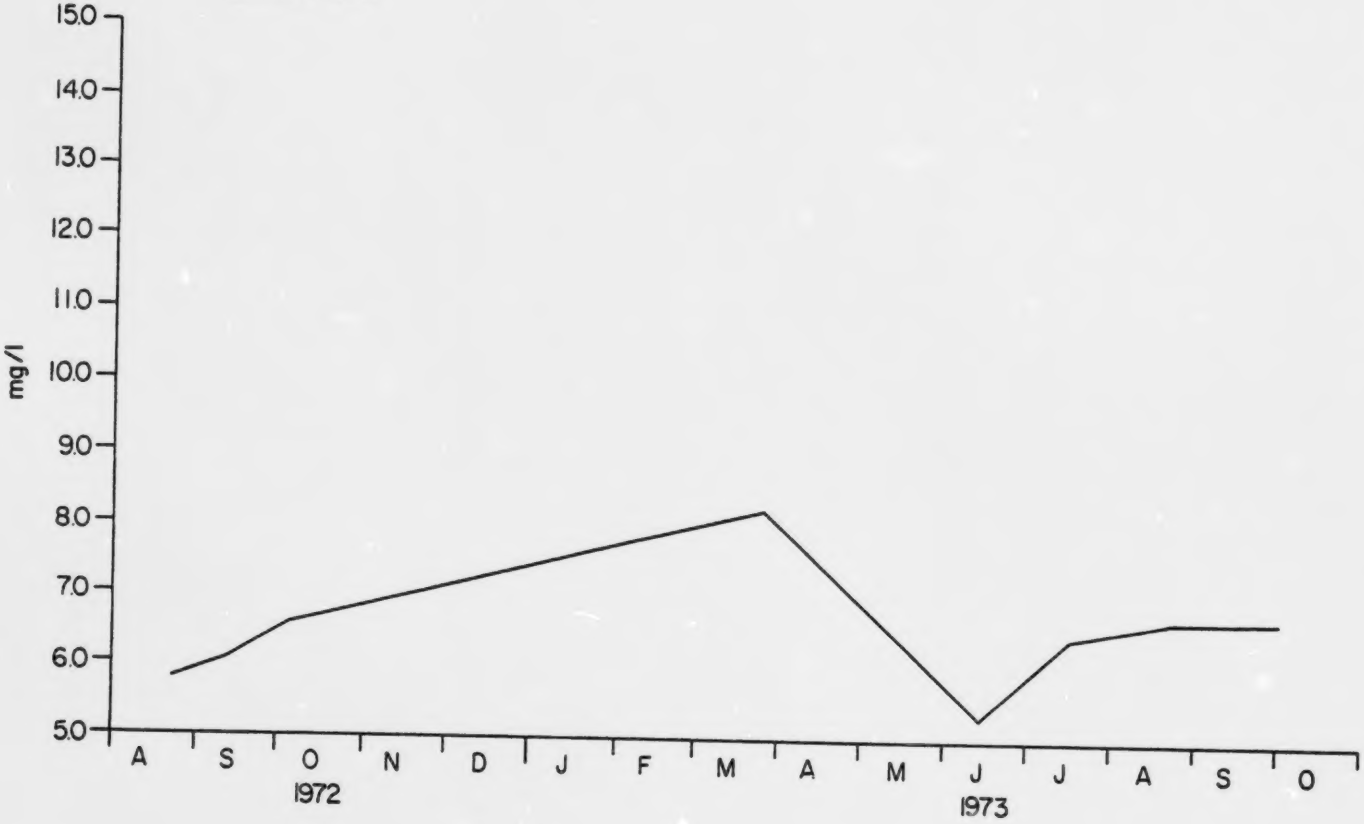
STATION 2, 1972 - 1973
POTASSIUM

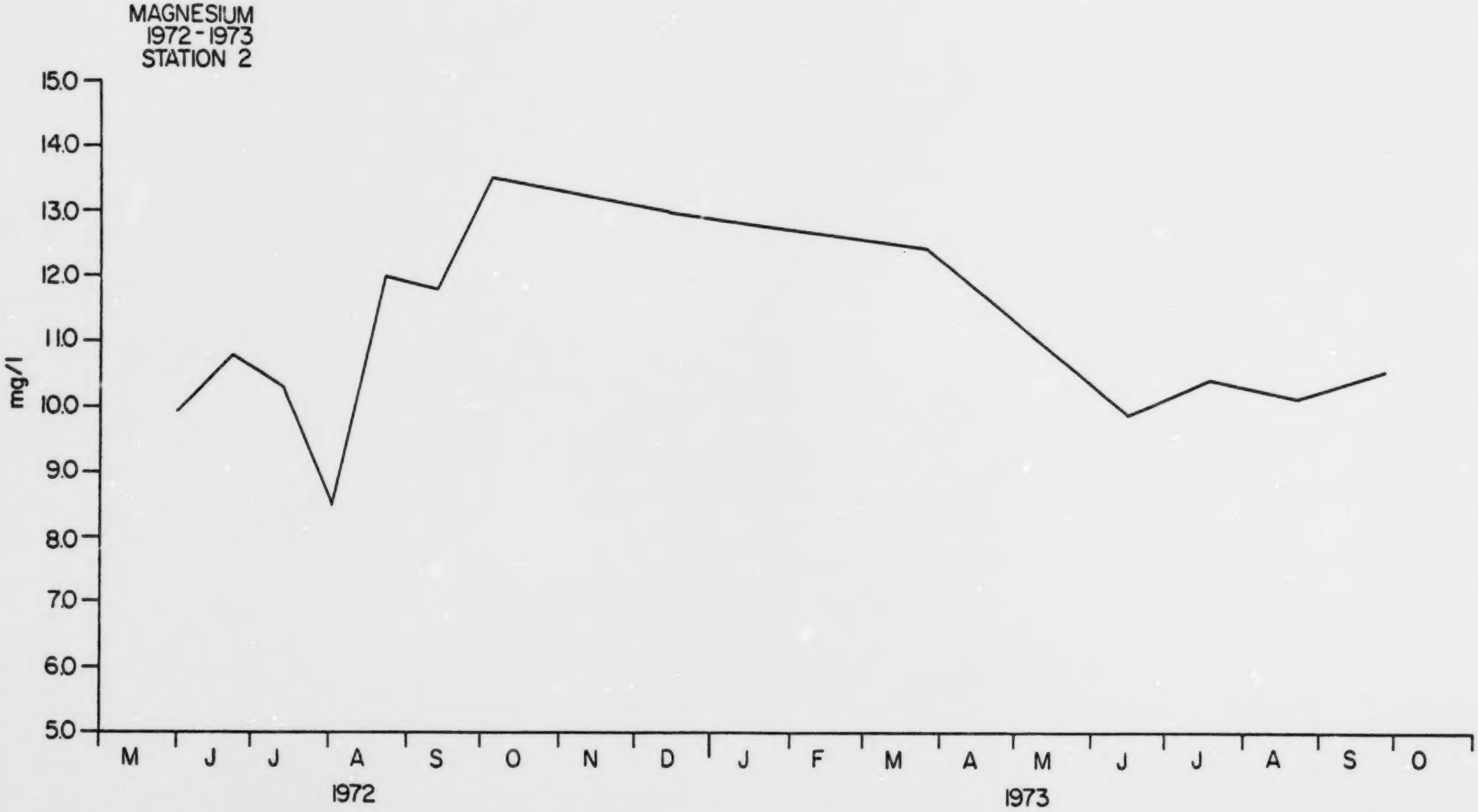


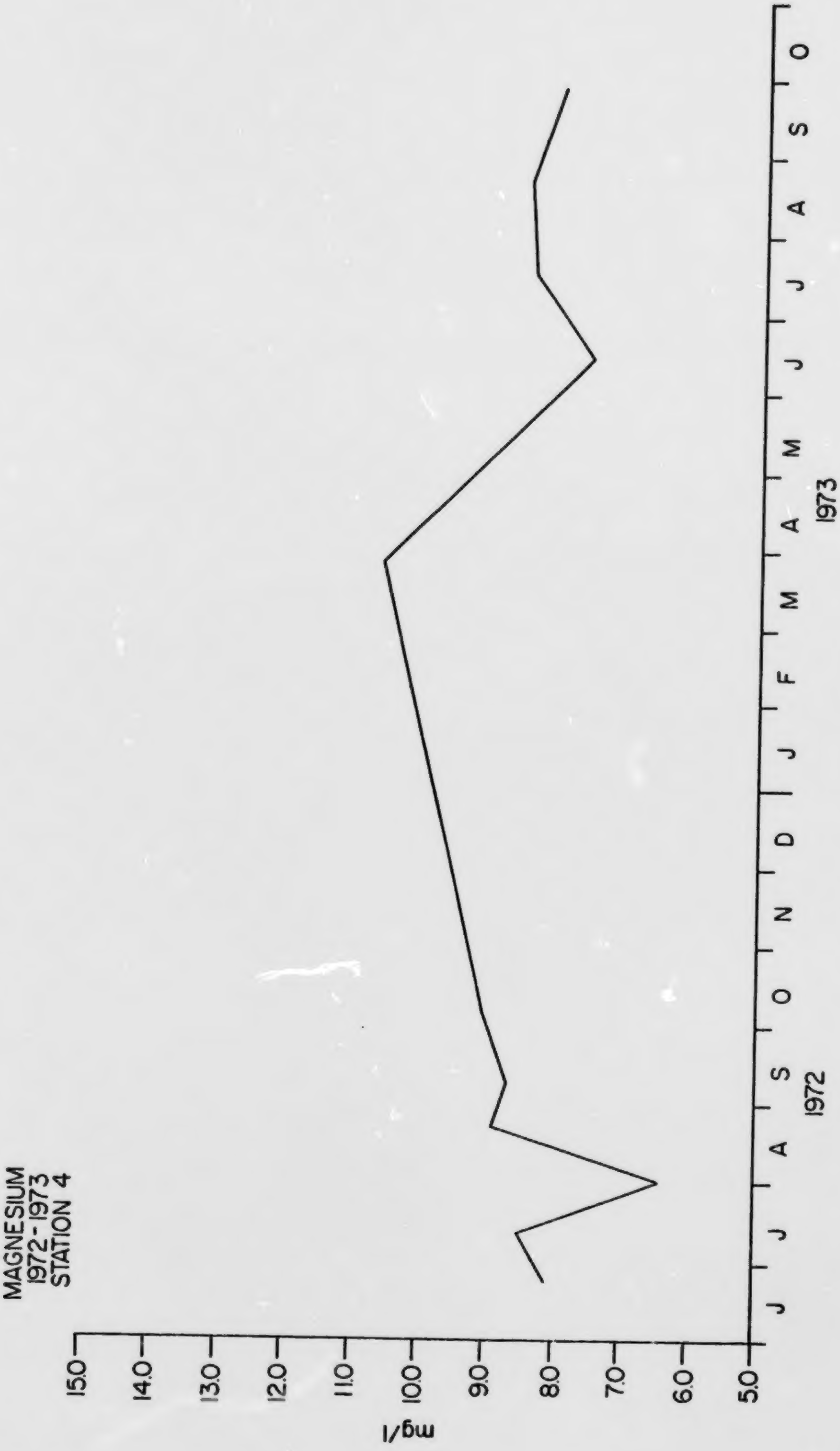

STATION 4, 1972 - 73
POTASSIUM
mg / l
3.5
3.0
2.5
2.0
1.5
1.0
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1972
1973

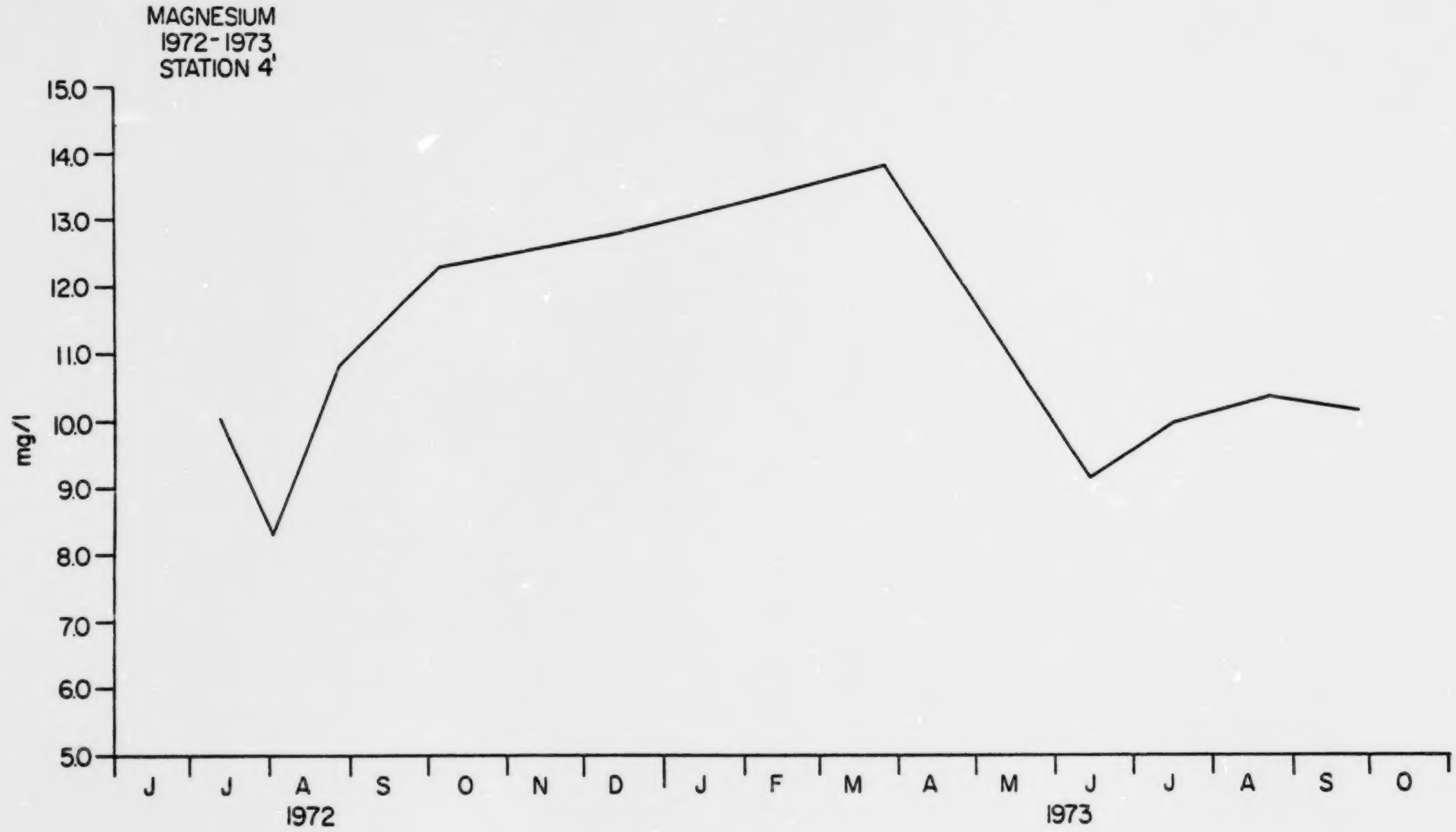


STATION 4', 1972 - 73
POTASSIUM

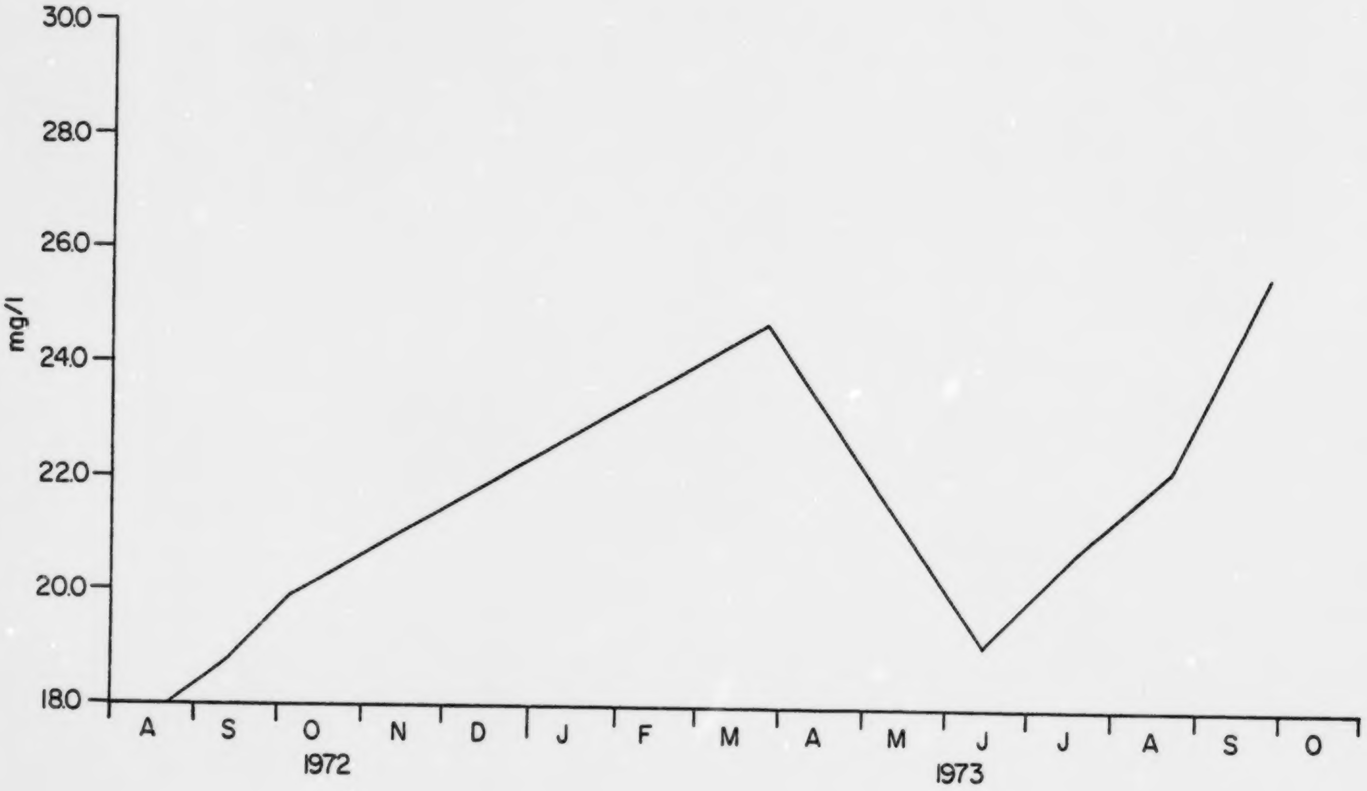

MAGNESIUM
1972 - 1973
STATION 200


MAGNESIUM
1972 - 1973
STATION 2
mg/l
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
M
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

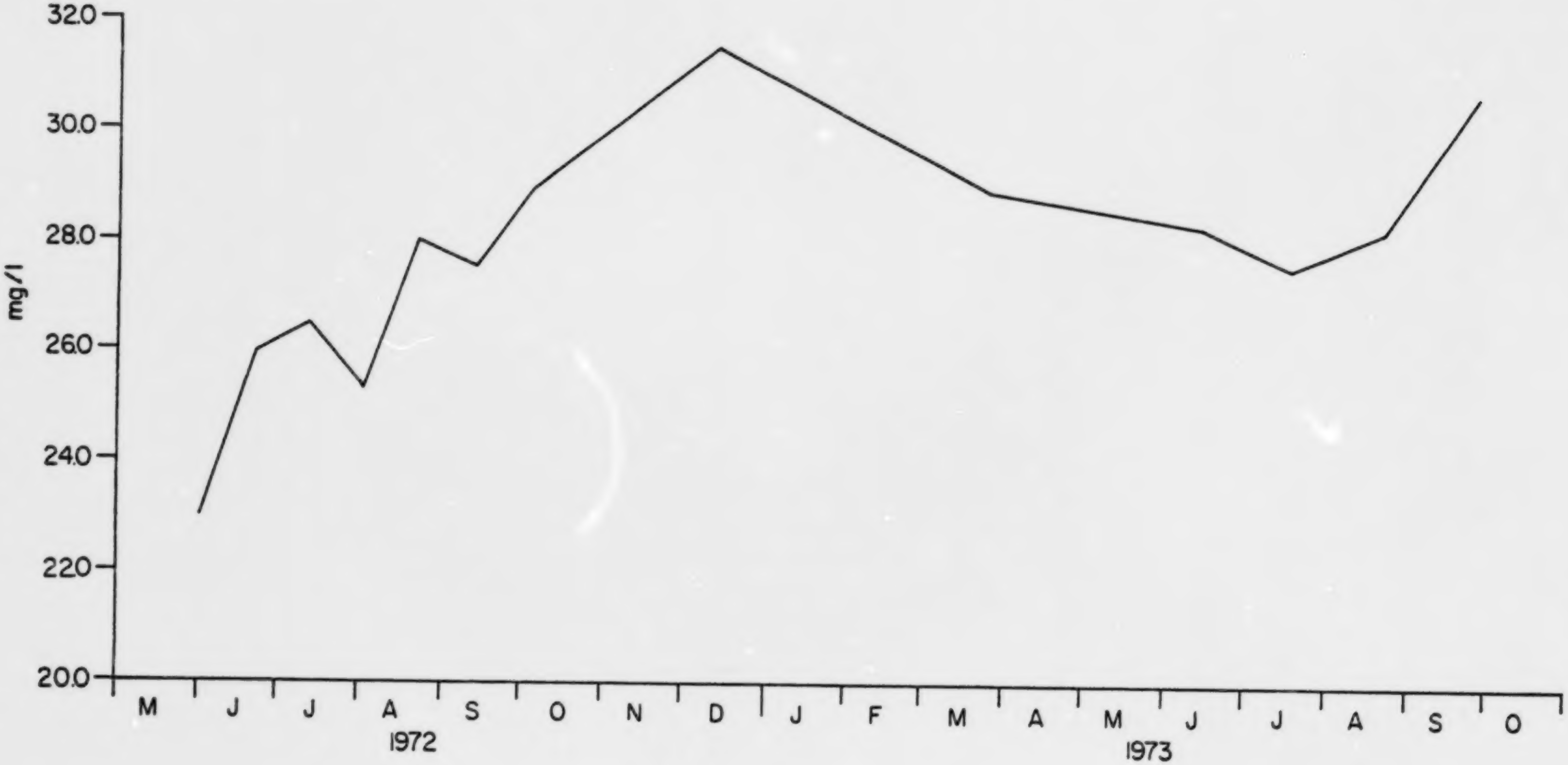

MAGNESIUM
1972-1973
STATION 4
mg/l
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

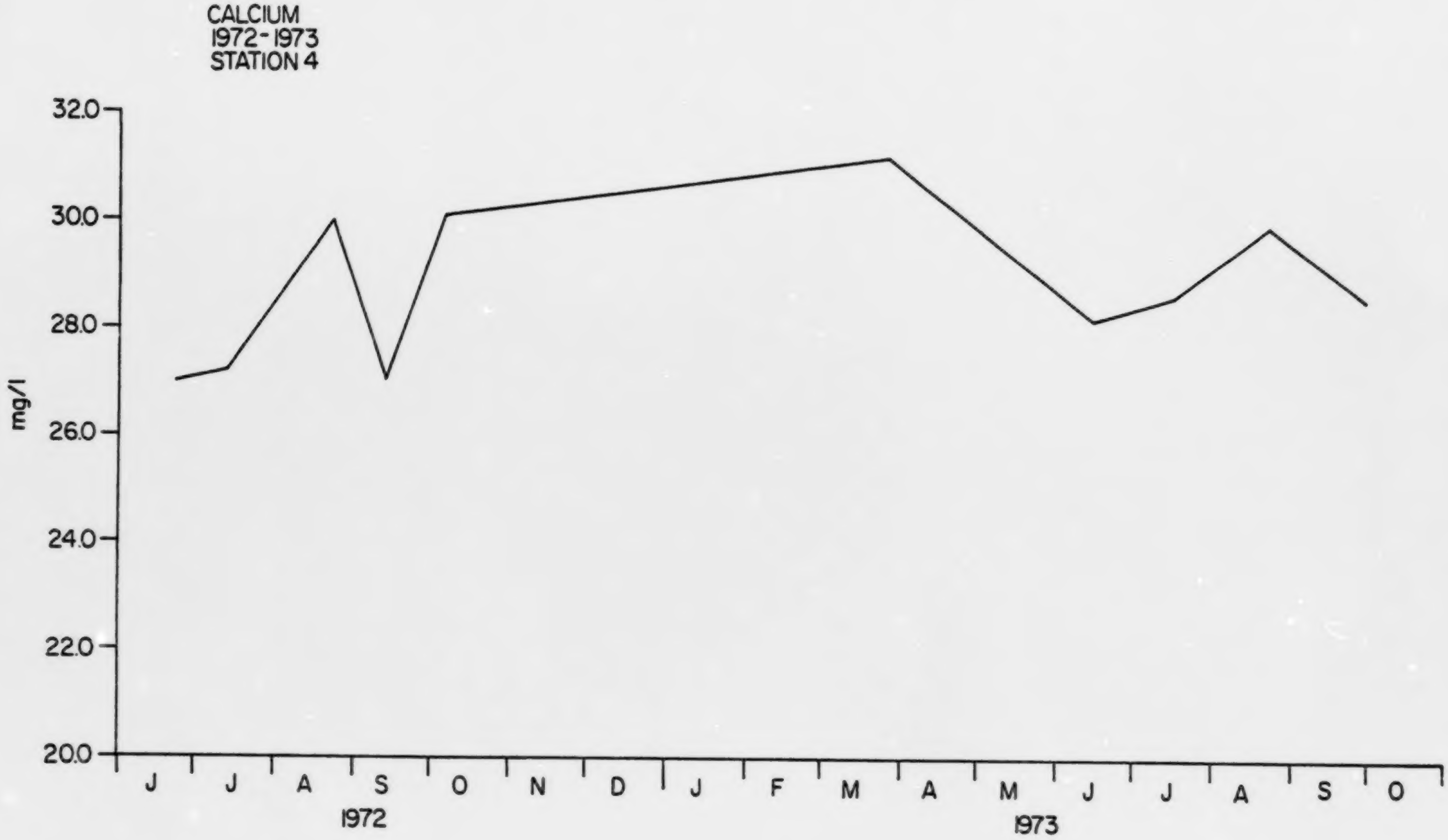

MAGNESIUM
1972-1973
STATION 4'
mg/l
15.0
14.0
13.0
12.0
11.0
10.0
9.0
8.0
7.0
6.0
5.0
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

CALCIUM
1972 - 1973
STATION 200

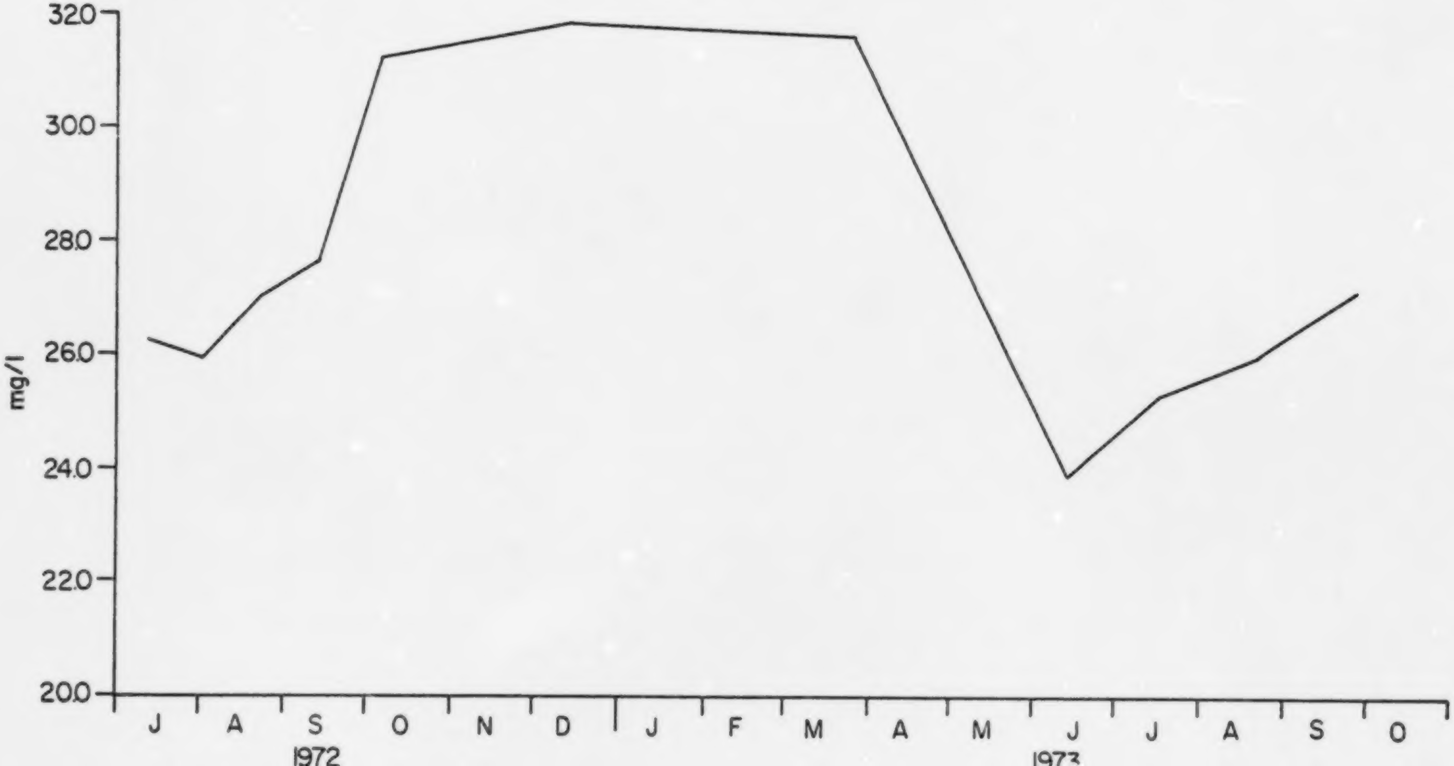


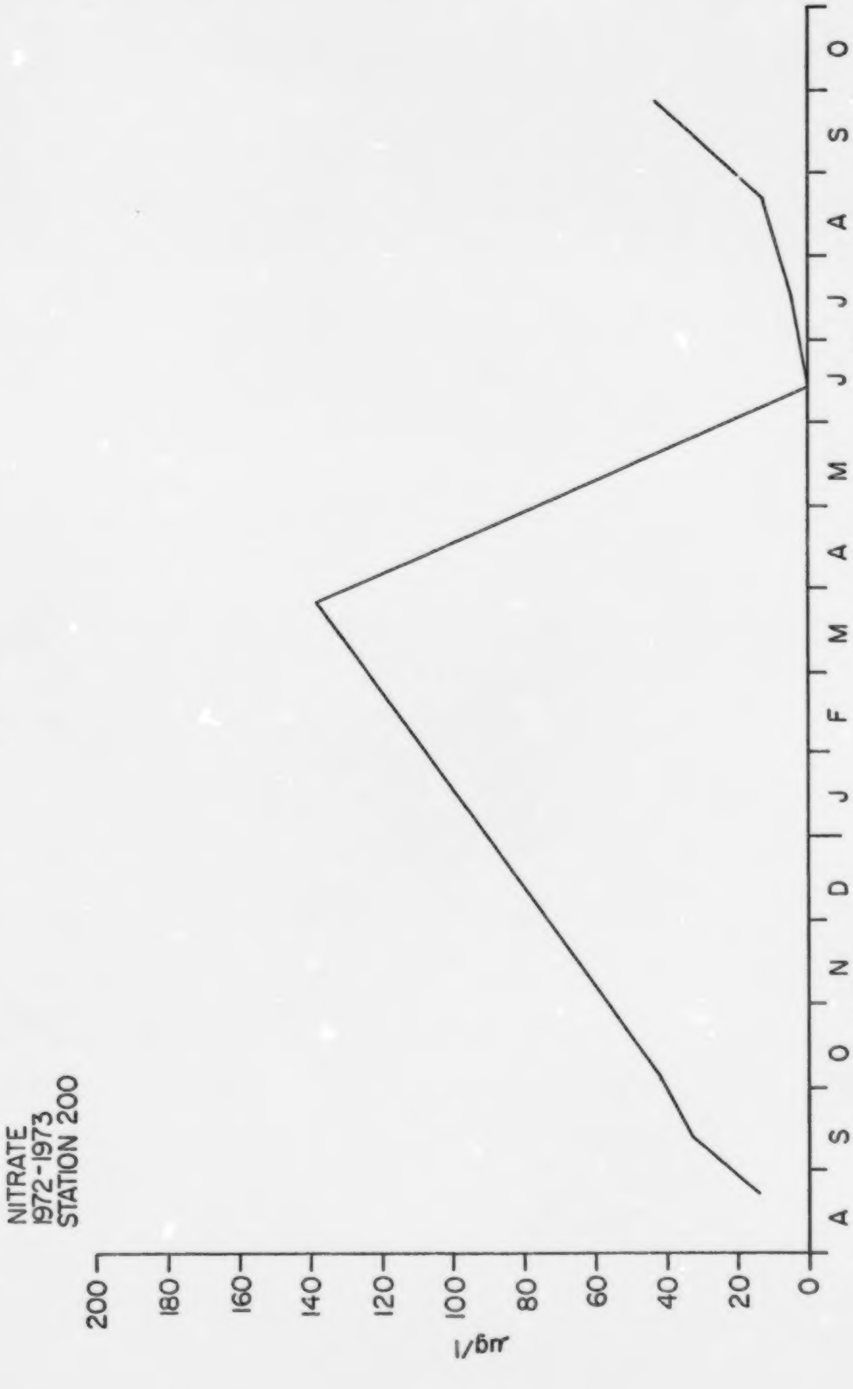
CALCIUM
1972 - 1973
STATION 2

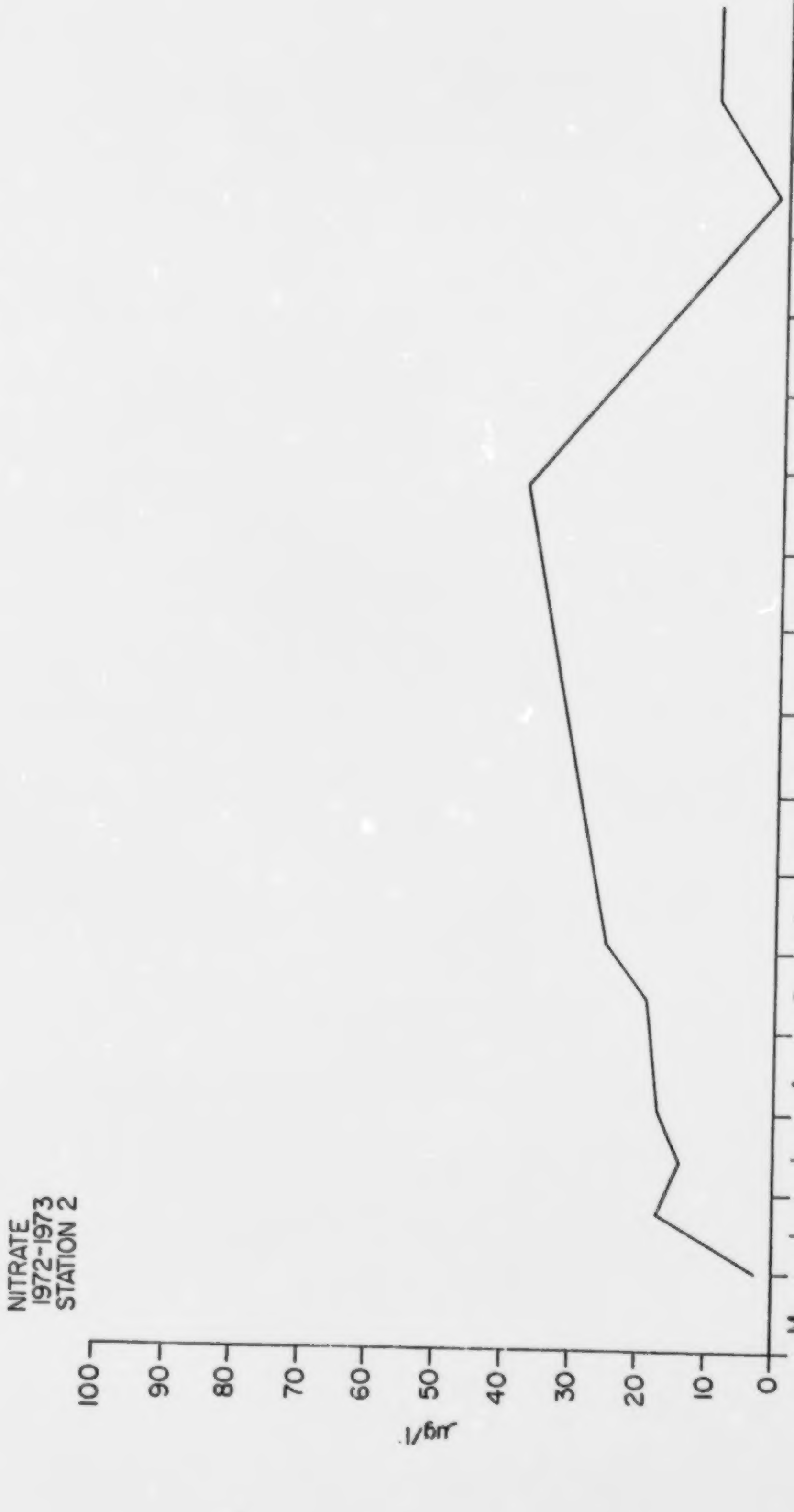


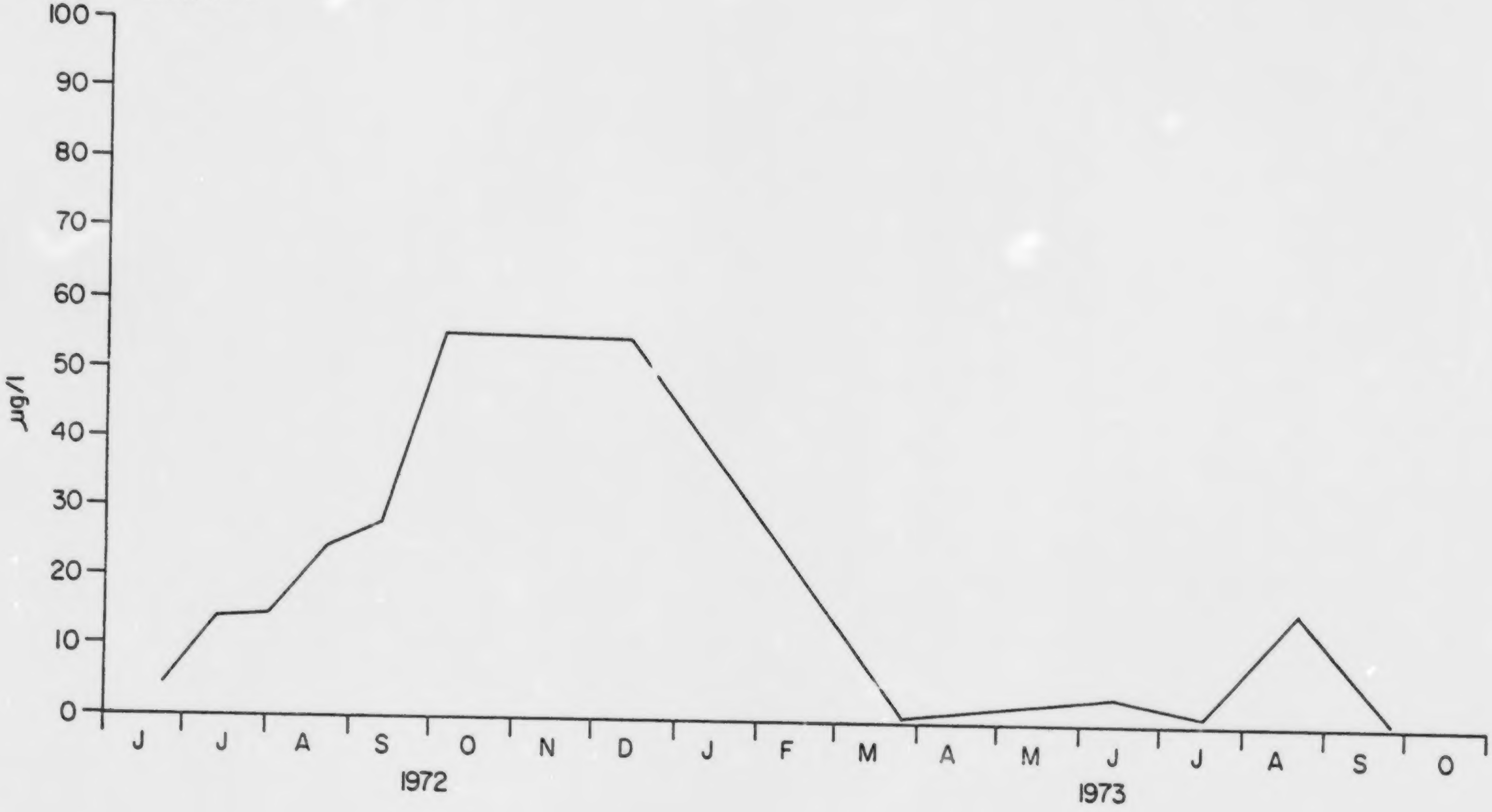

CALCIUM
1972-1973
STATION 4
mg/l
32.0
30.0
28.0
26.0
24.0
22.0
20.0
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

CALCIUM
1972-1973
STATION 4'

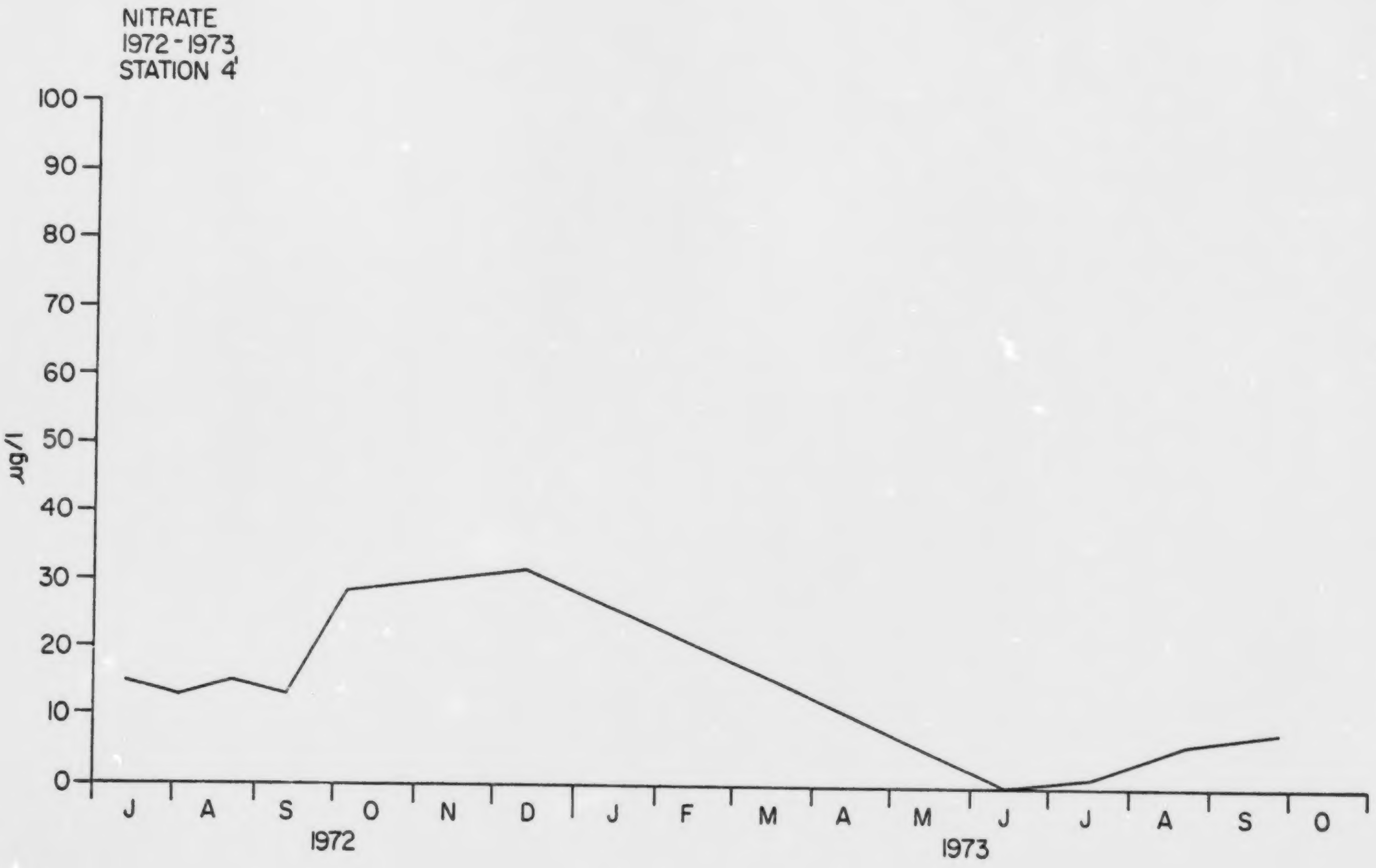


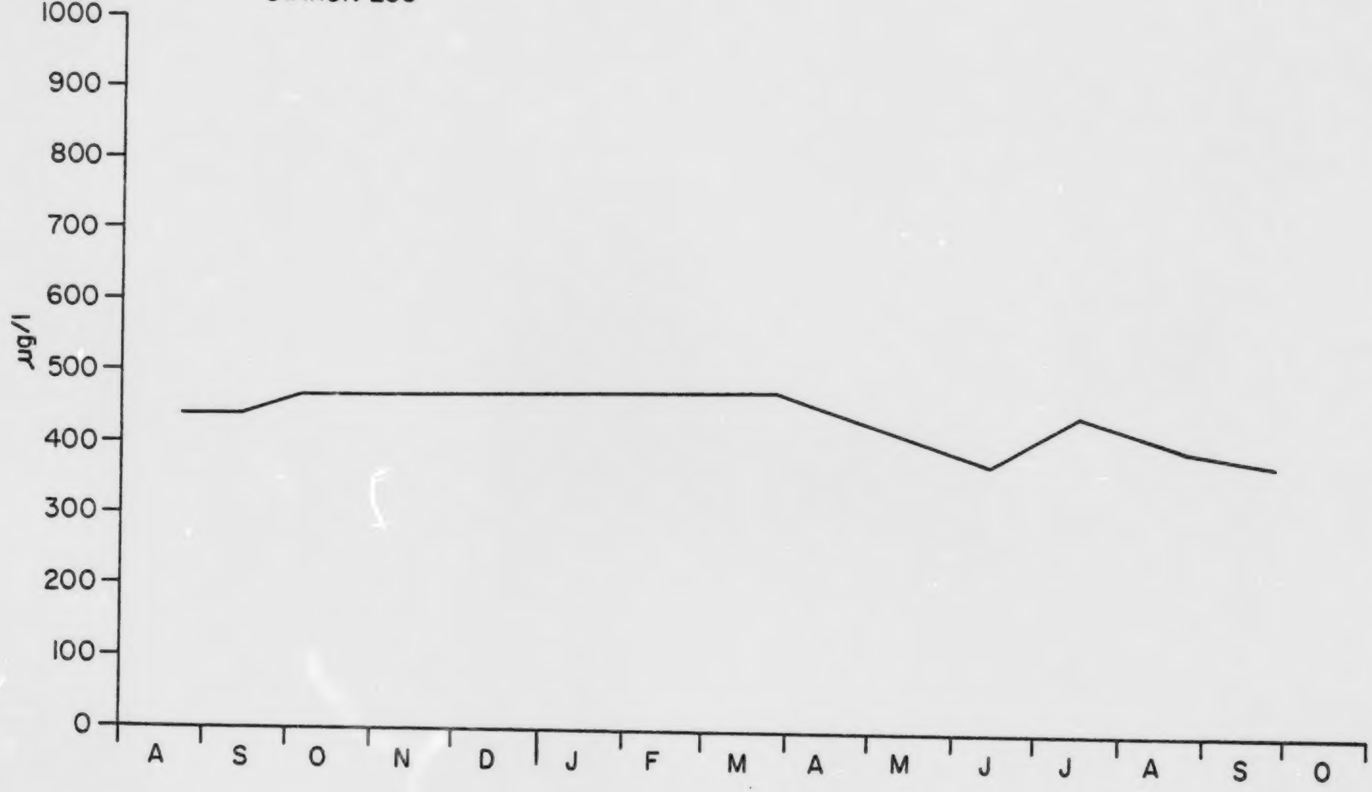

NITRATE
1972-1973
STATION 200
μg/l
0
20
40
60
80
100
120
140
160
180
200
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973


NITRATE
1972-1973
STATION 2
100
90
80
70
60
50
40
30
20
10
0
mg/l

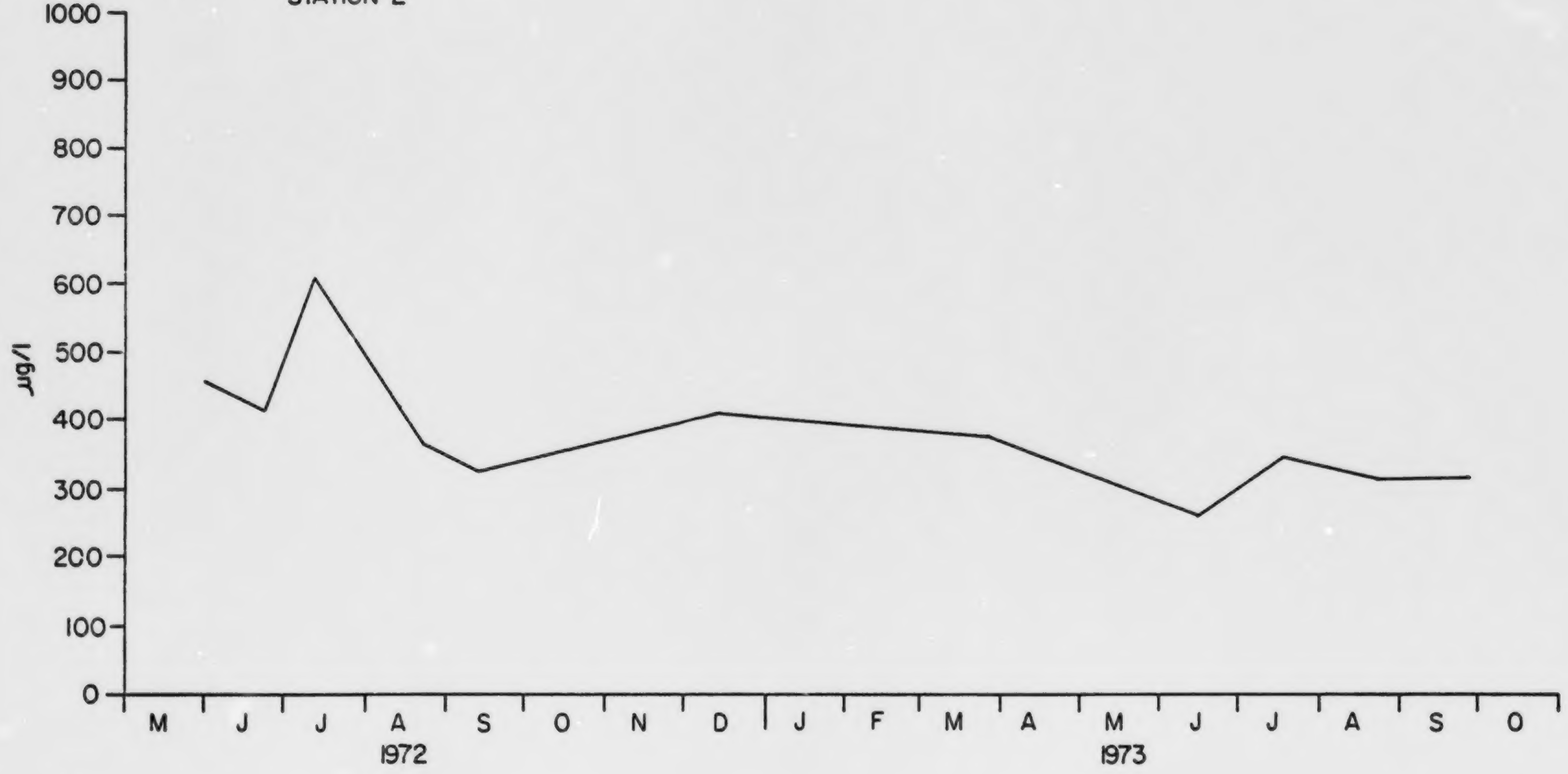


NITRATE
1972-1973
STATION 4

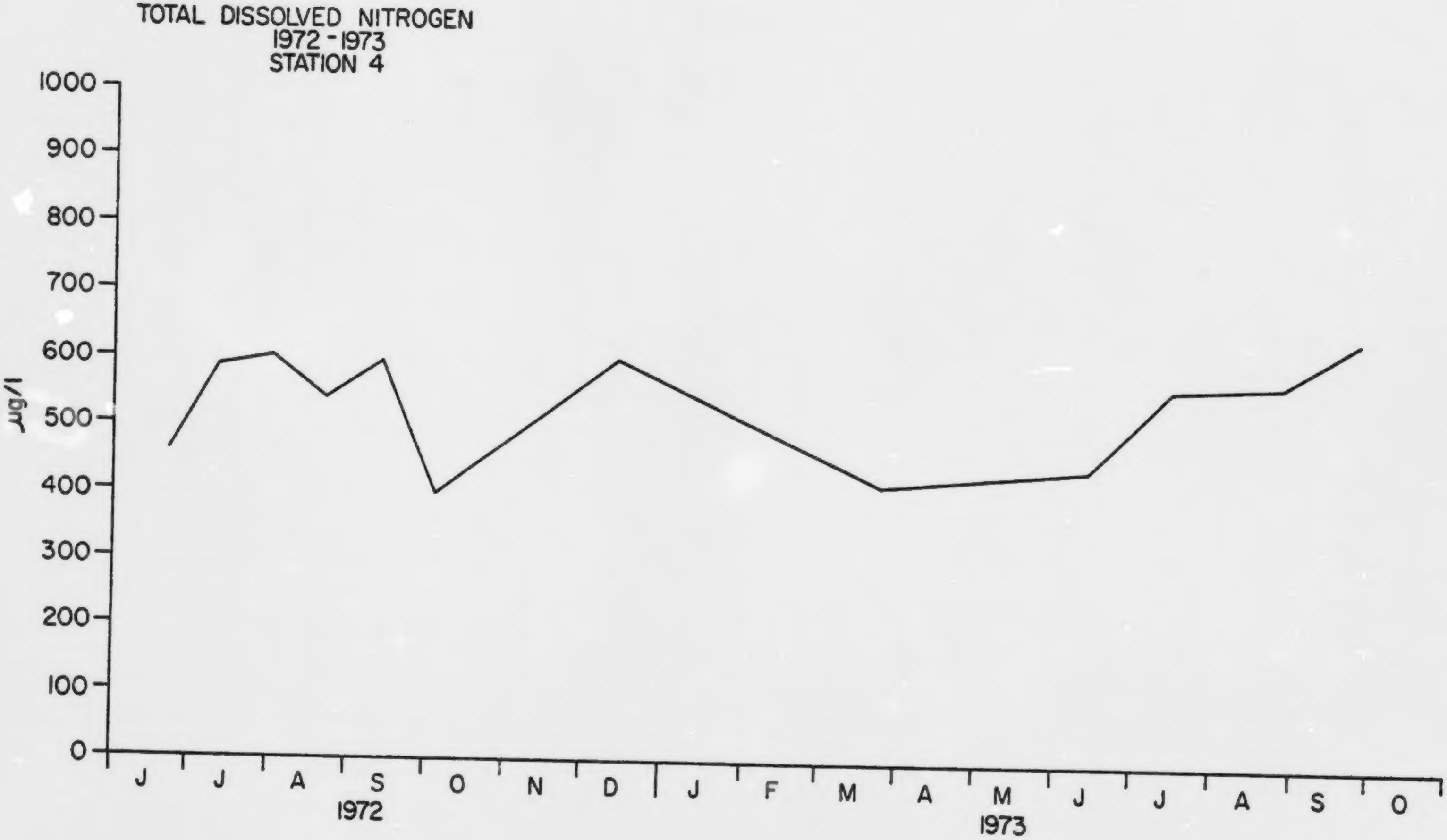

NITRATE
1972 - 1973
STATION 4'
µg/l
100
90
80
70
60
50
40
30
20
10
0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

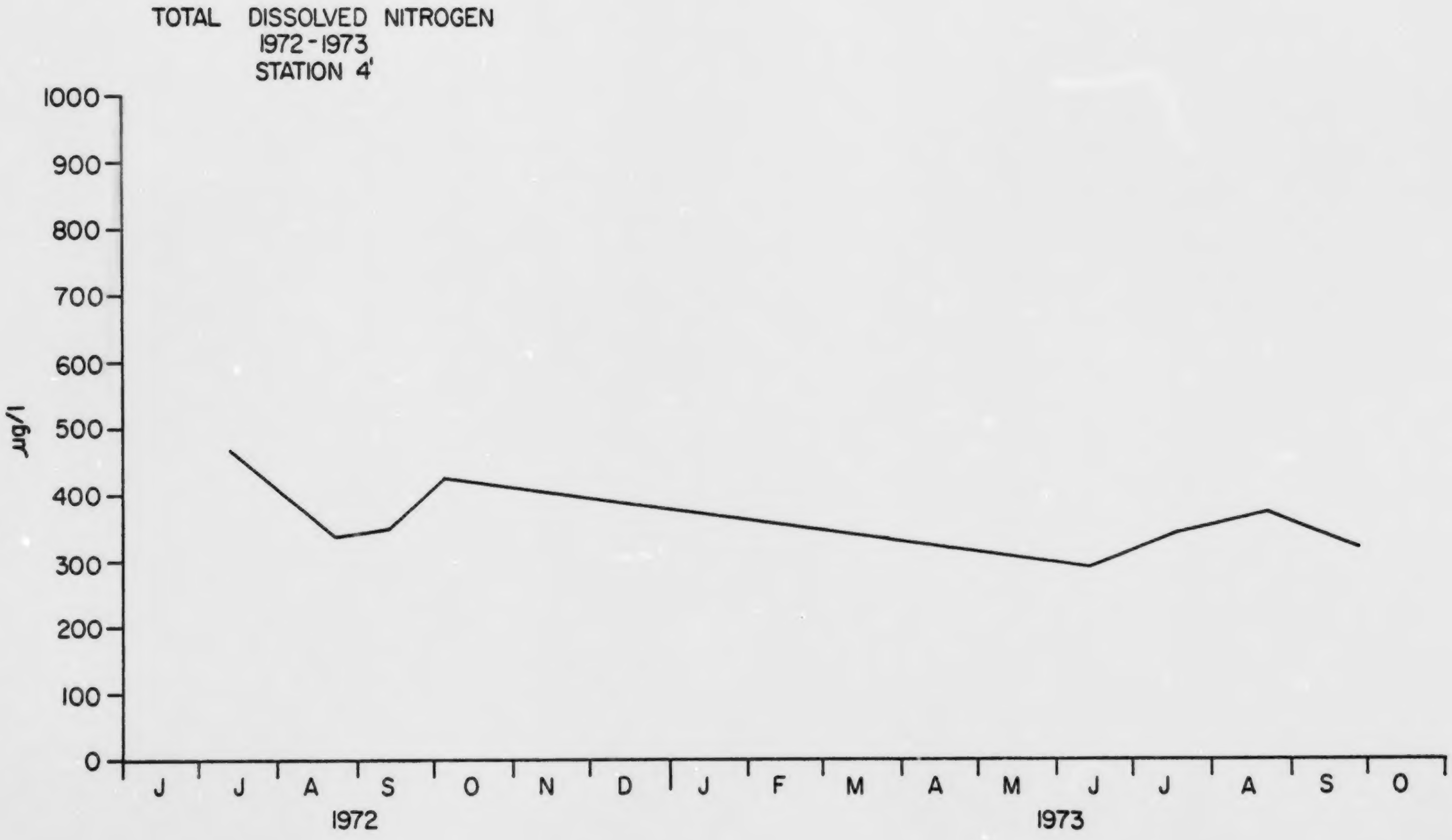


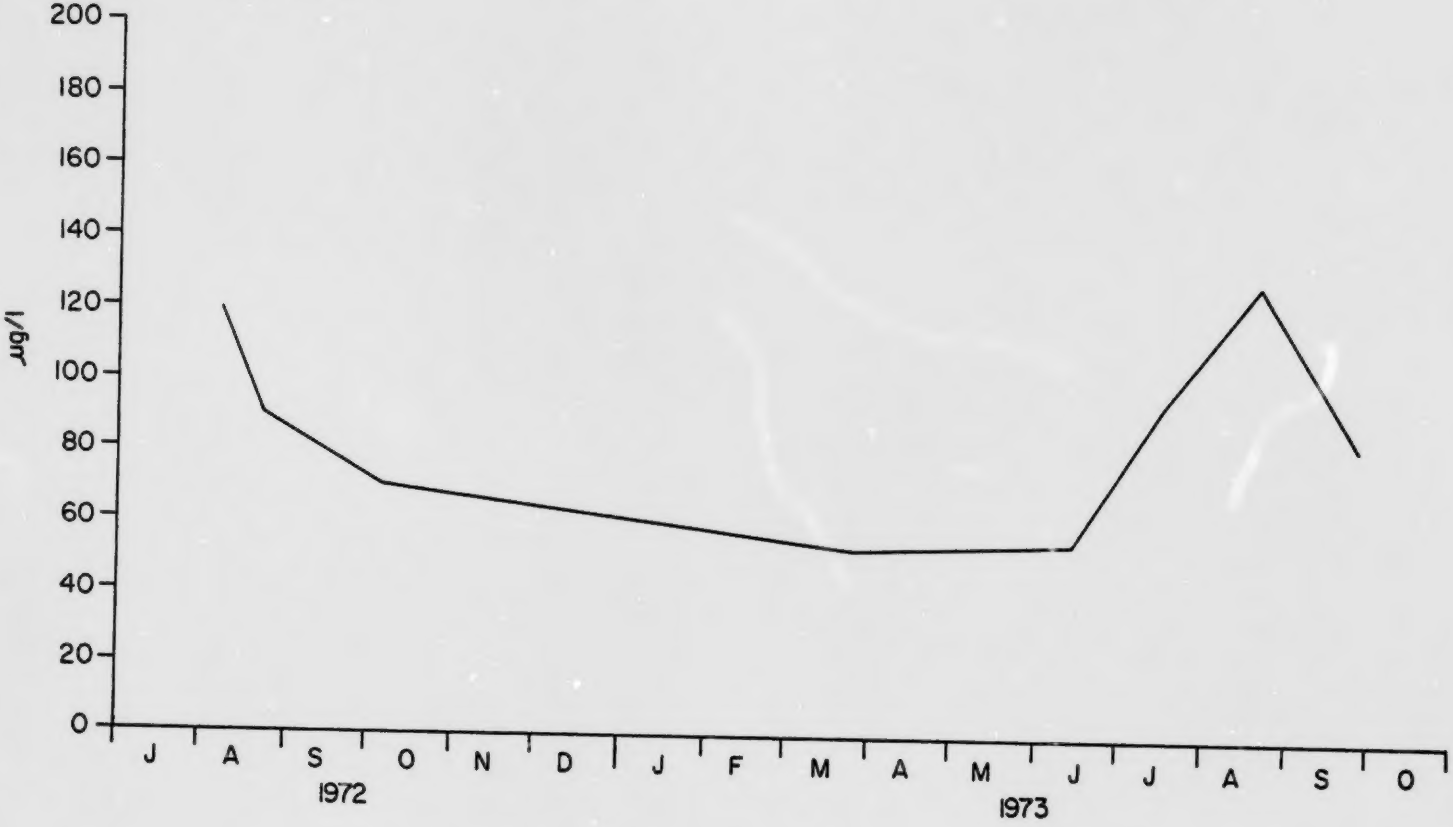
TOTAL DISSOLVED NITROGEN
1972 - 1973
STATION 200



TOTAL DISSOLVED NITROGEN
1972 - 1973
STATION 2

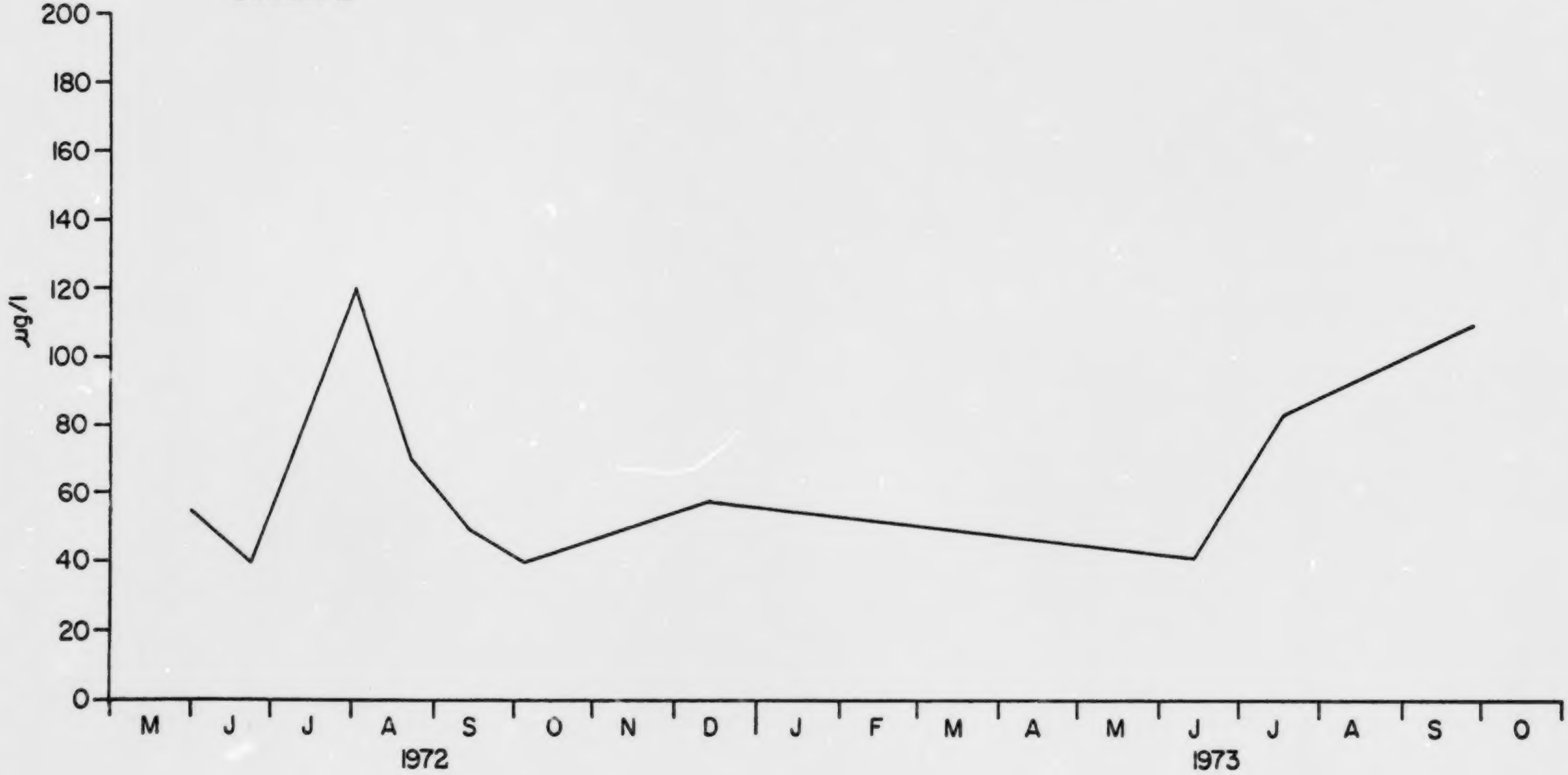

TOTAL DISSOLVED NITROGEN
1972 - 1973
STATION 4
μg/l
1000
900
800
700
600
500
400
300
200
100
0
J
J
A
S
1972
O
N
D
J
F
M
A
M
1973
J
J
A
S
O

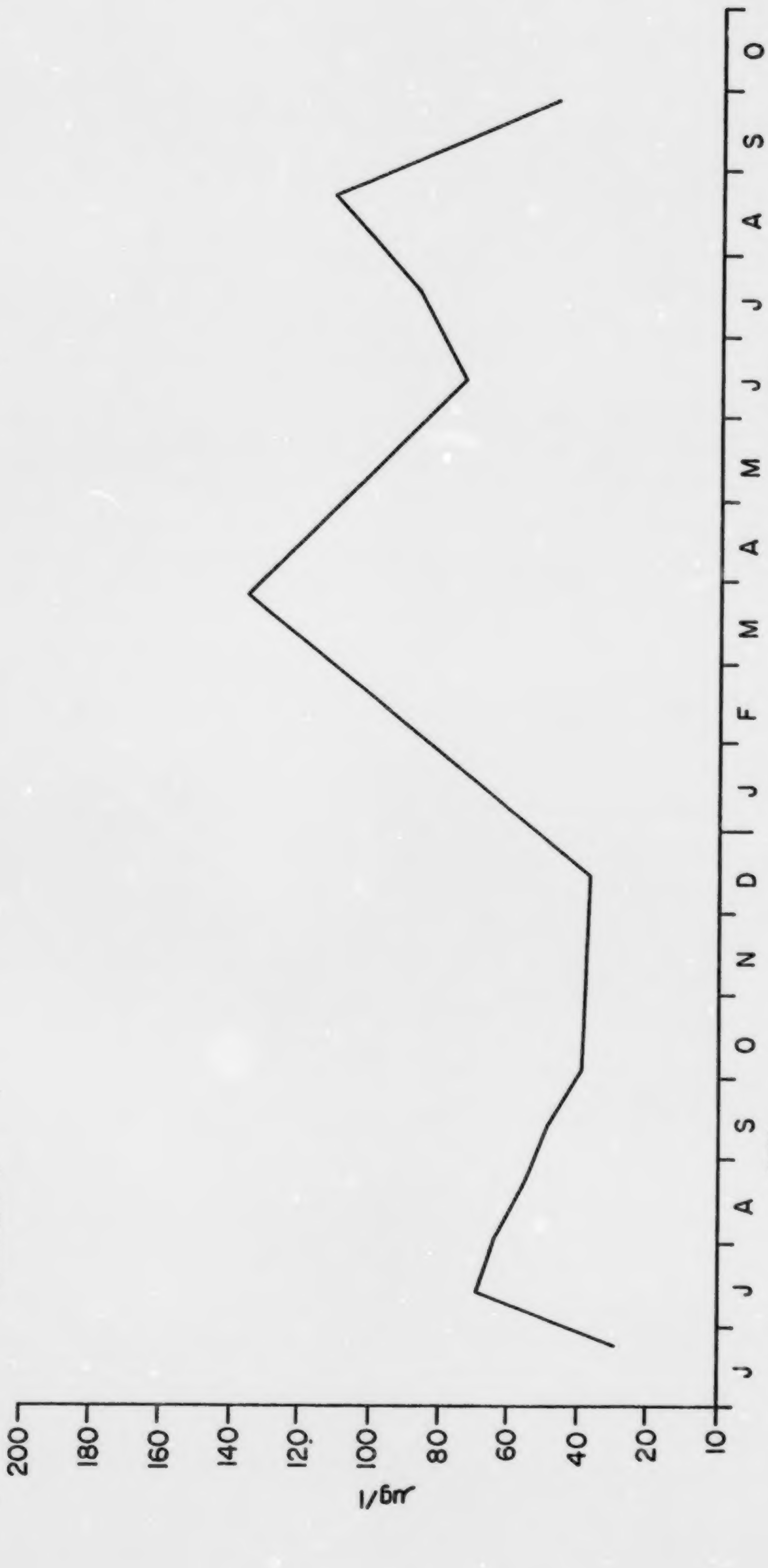

TOTAL DISSOLVED NITROGEN
1972-1973
STATION 4'
μg/l
1000
900
800
700
600
500
400
300
200
100
0
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973



SUSPENDED NITROGEN
1972 - 1973
STATION 200

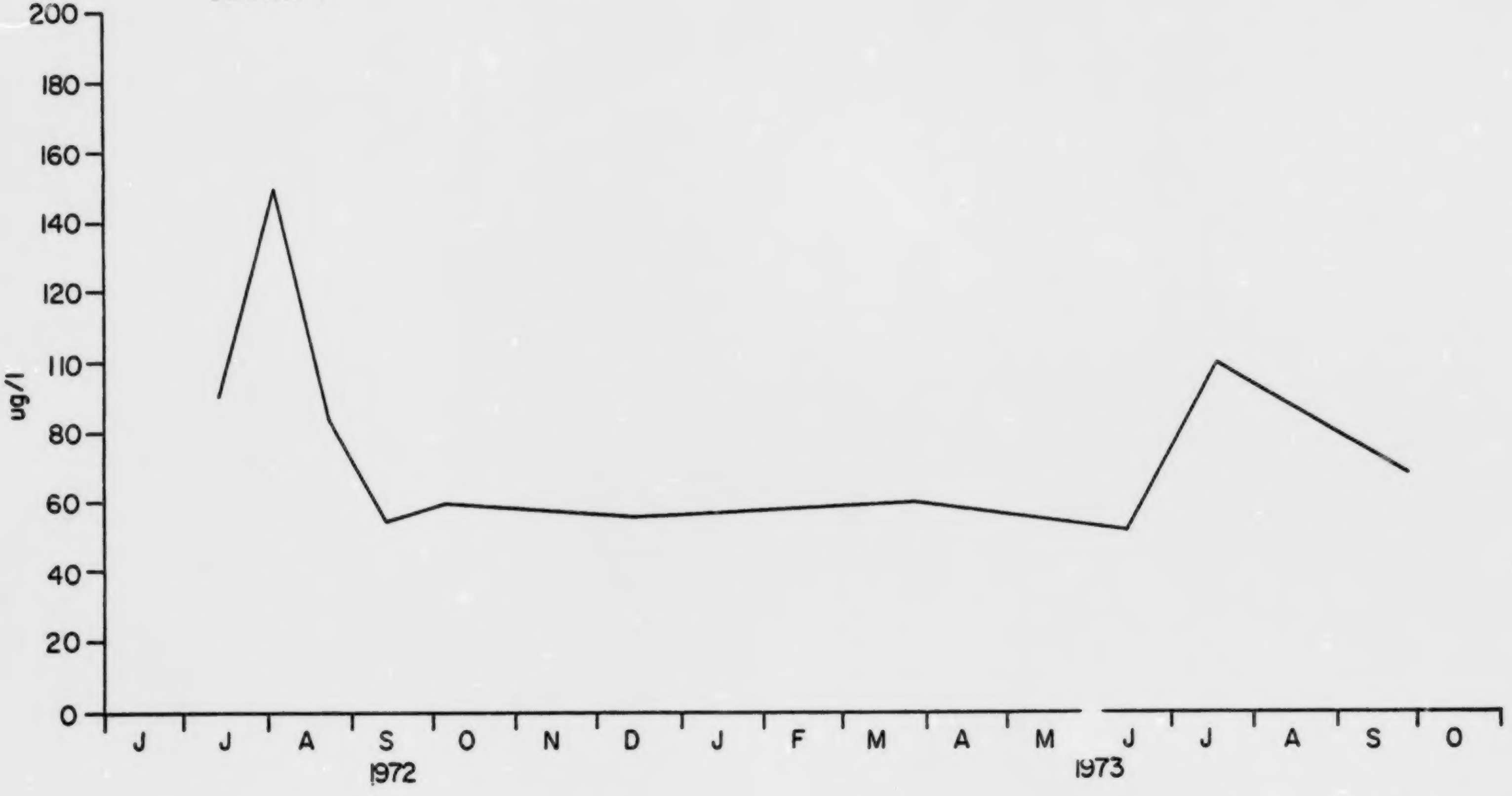
SUSPENDED NITROGEN
1972 - 1973
STATION 2



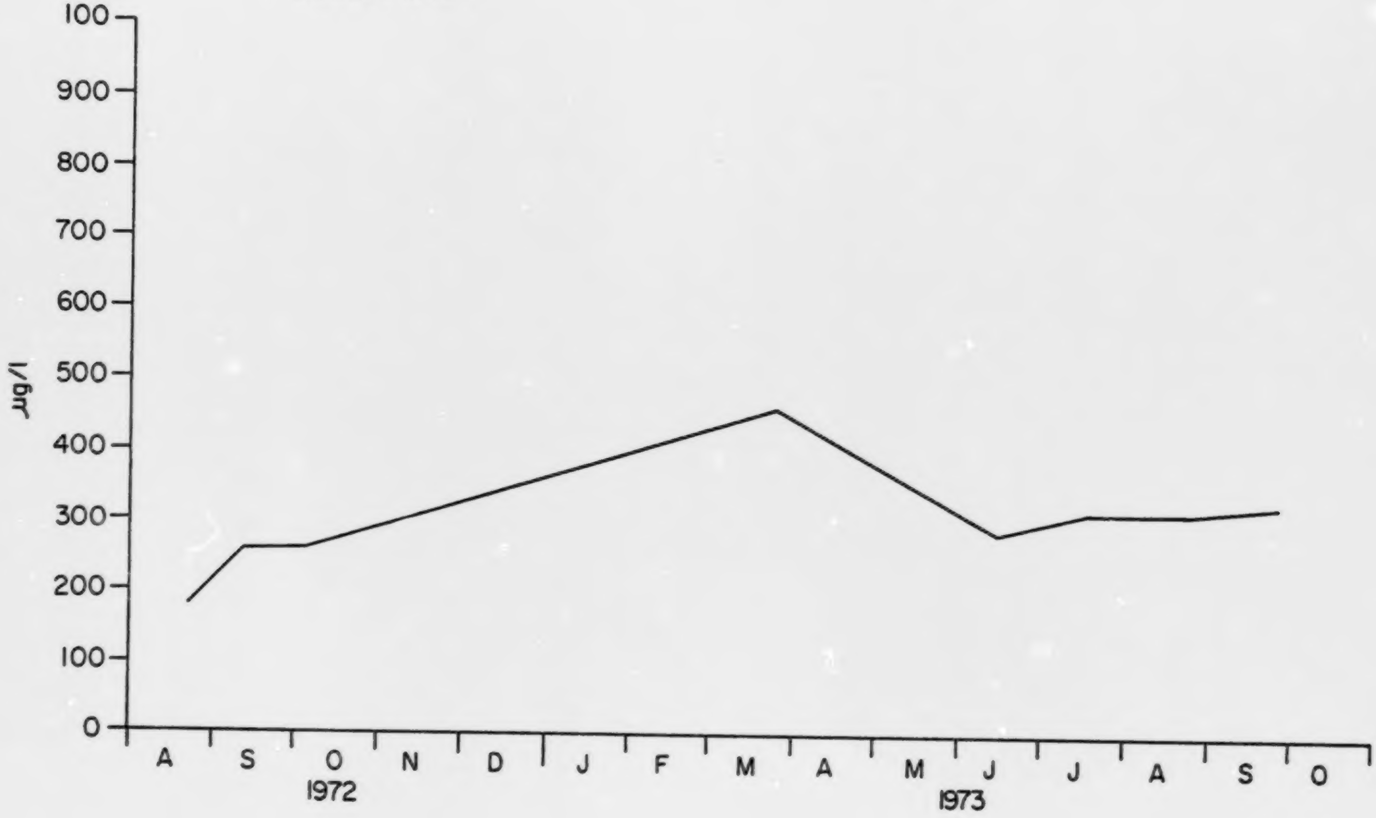


SUSPENDED NITROGEN
1972 - 1973
STATION 4

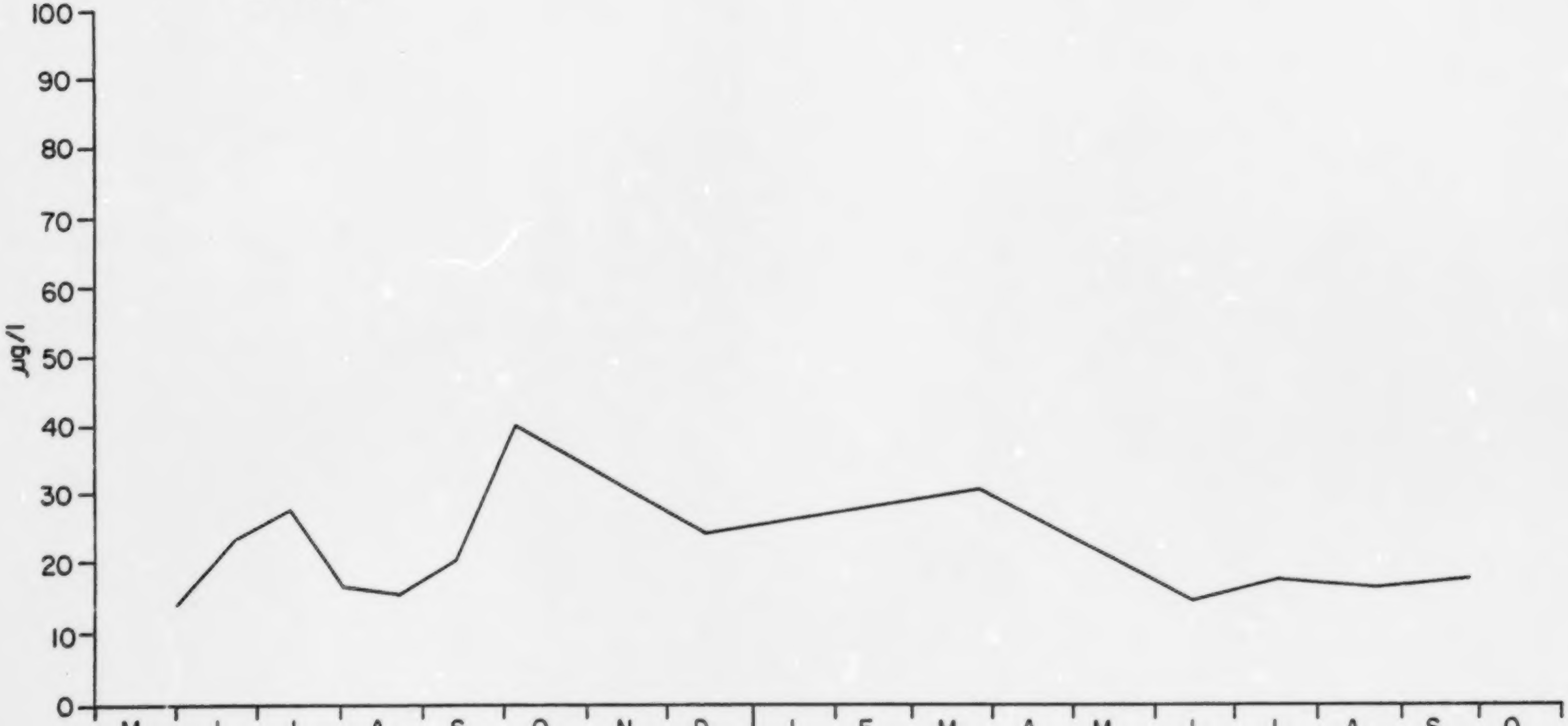
SUSPENDED NITROGEN
1972 - 1973
STATION 4'

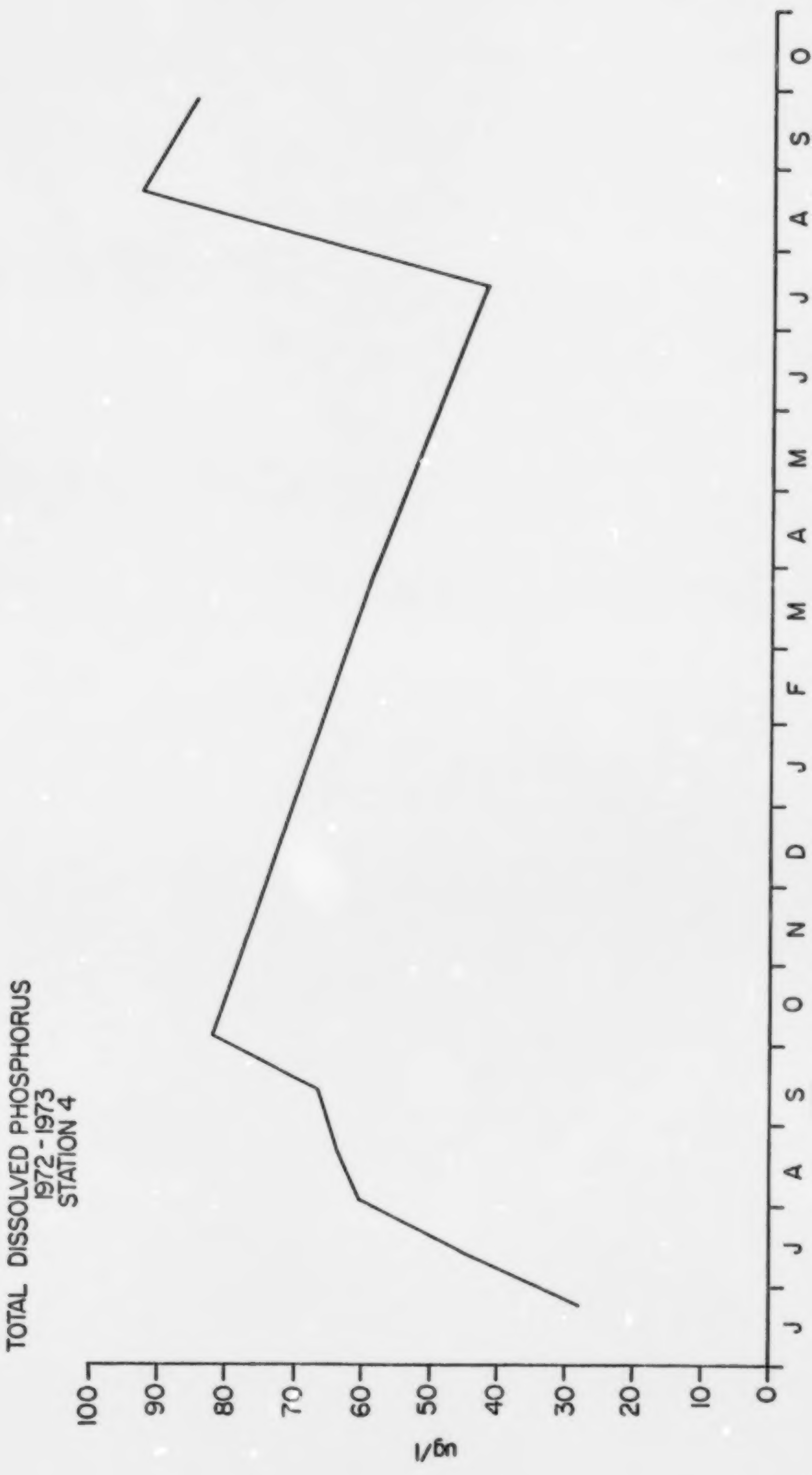


TOTAL DISSOLVED PHOSPHORUS
1972 - 1973
STATION 200

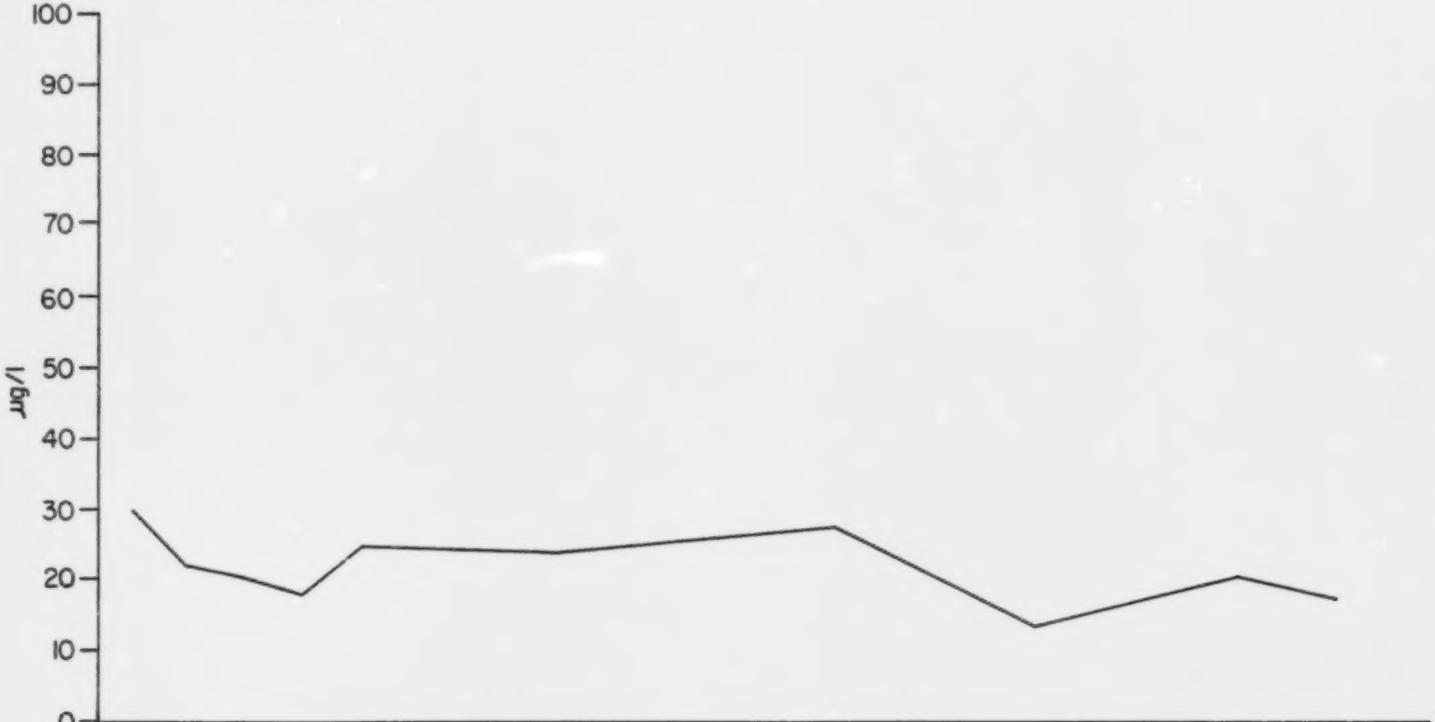


TOTAL DISSOLVED PHOSPHORUS
1972 - 1973
STATION 2



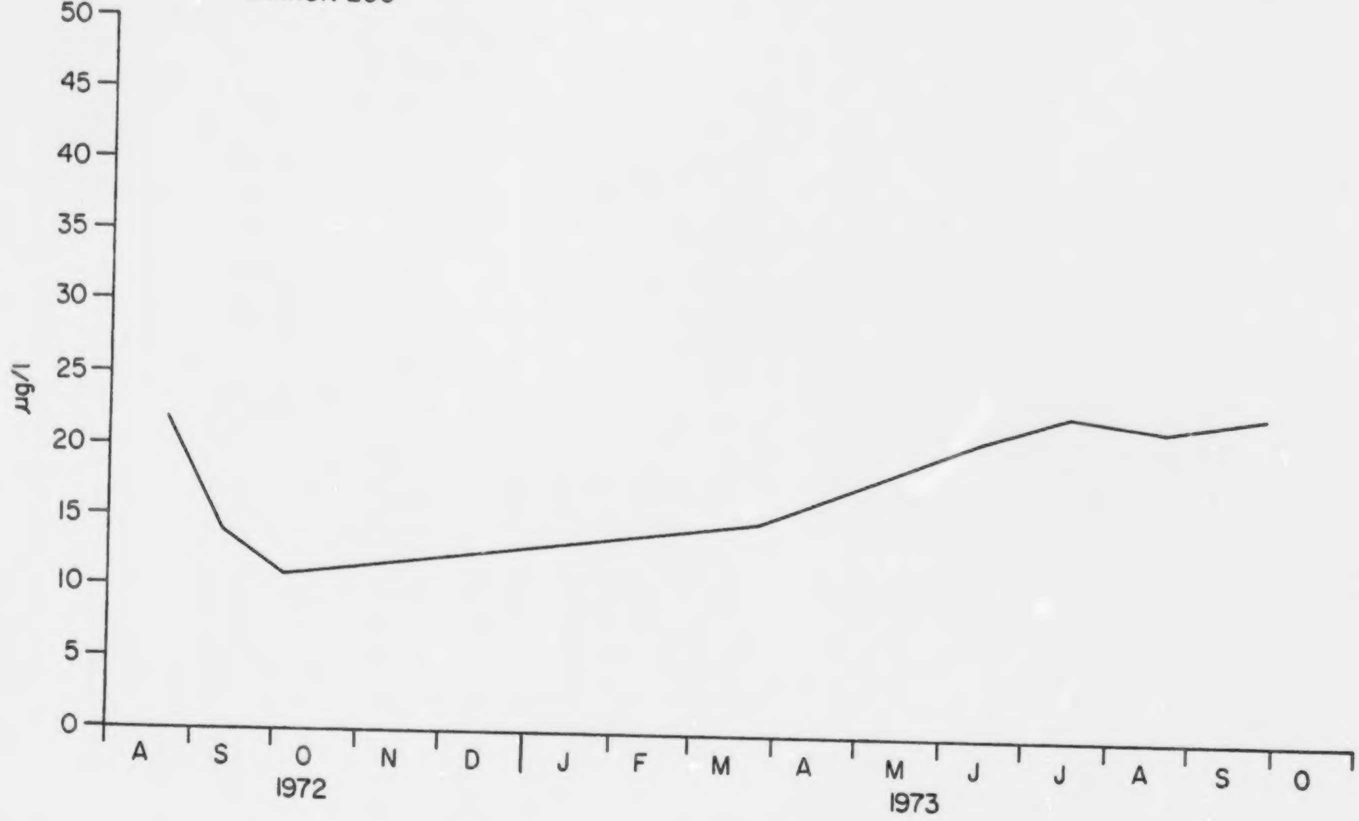


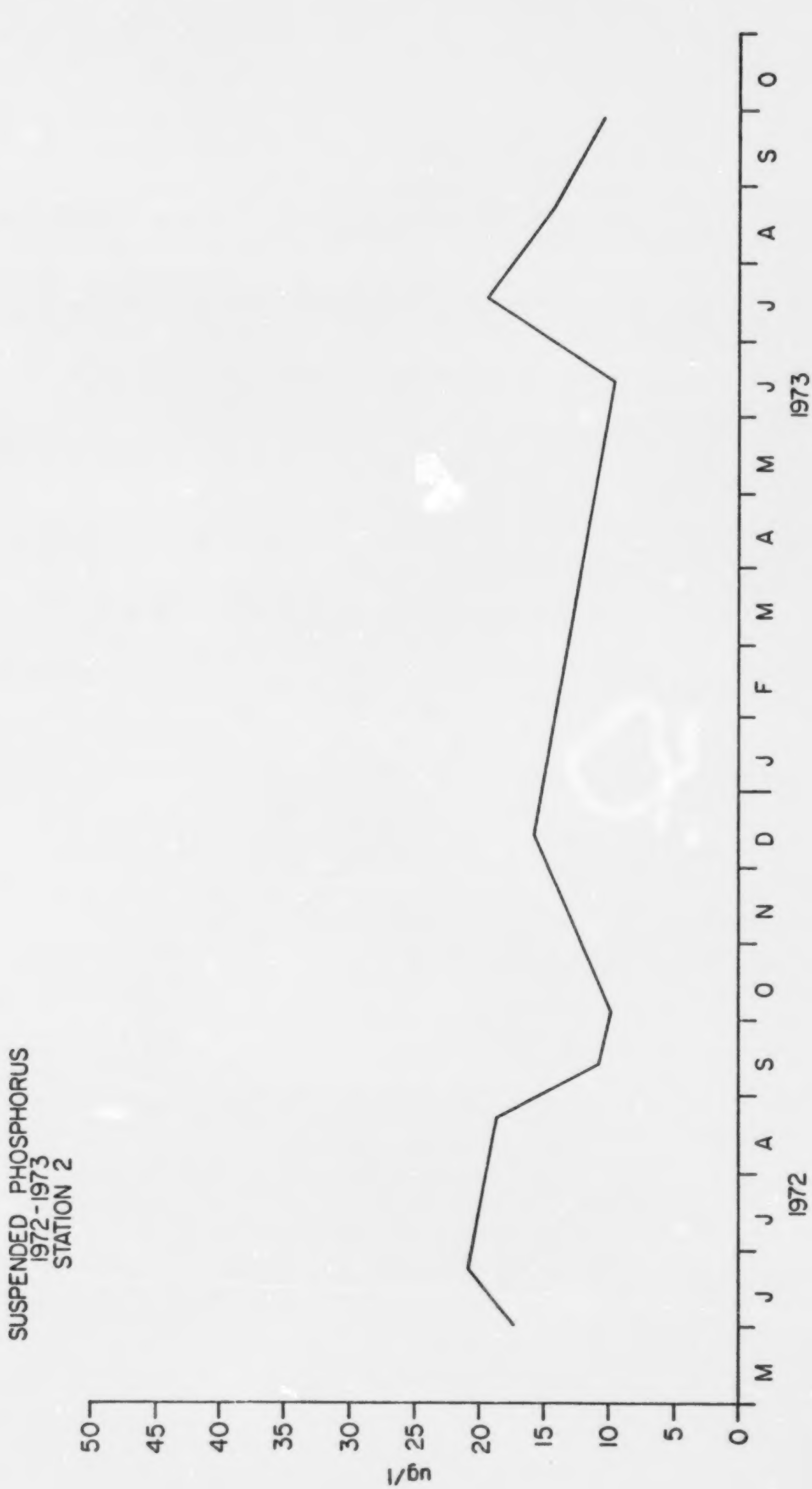
TOTAL DISSOLVED PHOSPHORUS
1972 - 1973
STATION 4



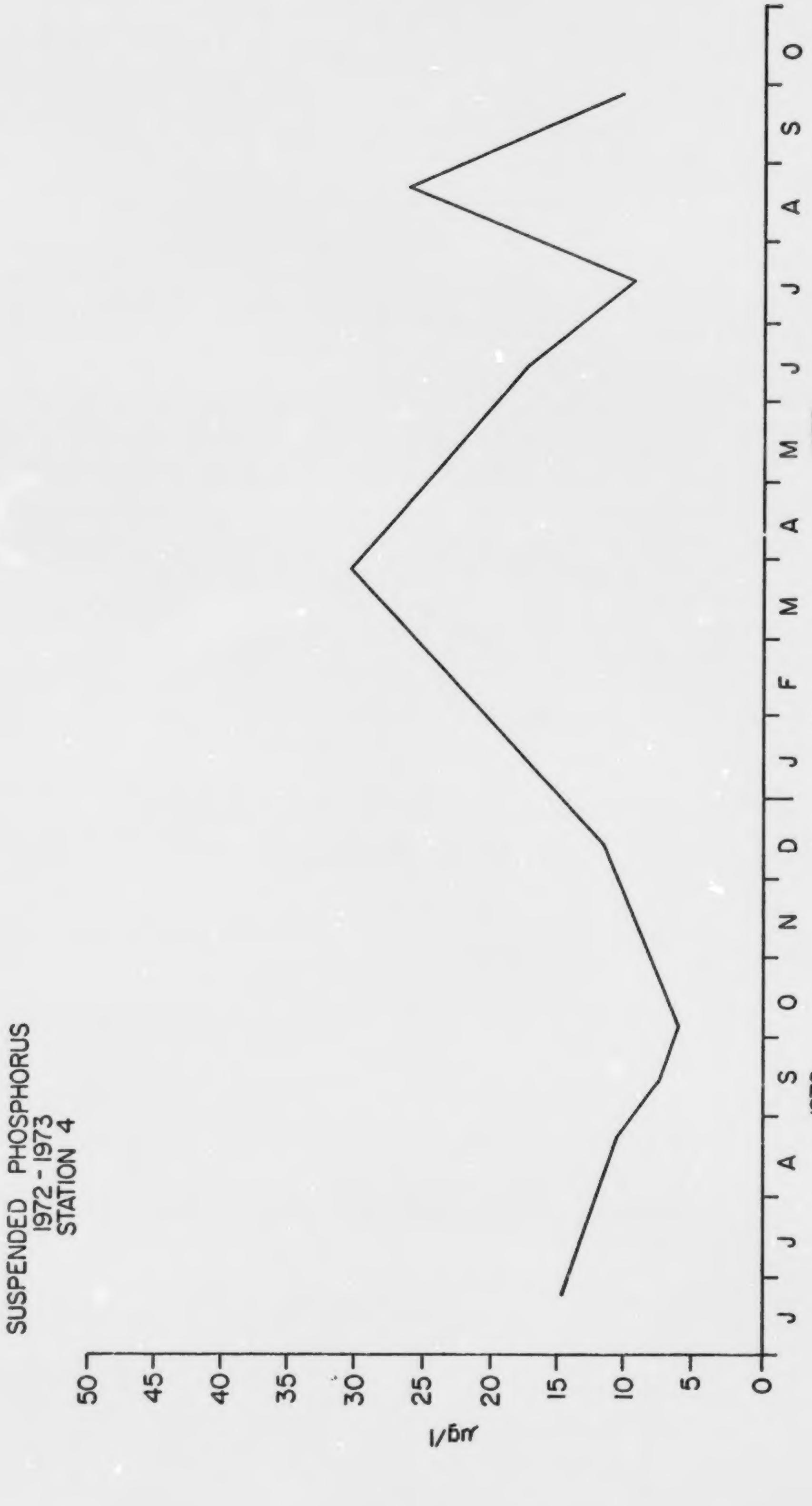
TOTAL DISSOLVED PHOSPHORUS
1972 - 1973
STATION 4'

SUSPENDED PHOSPHORUS
1972 - 1973
STATION 200

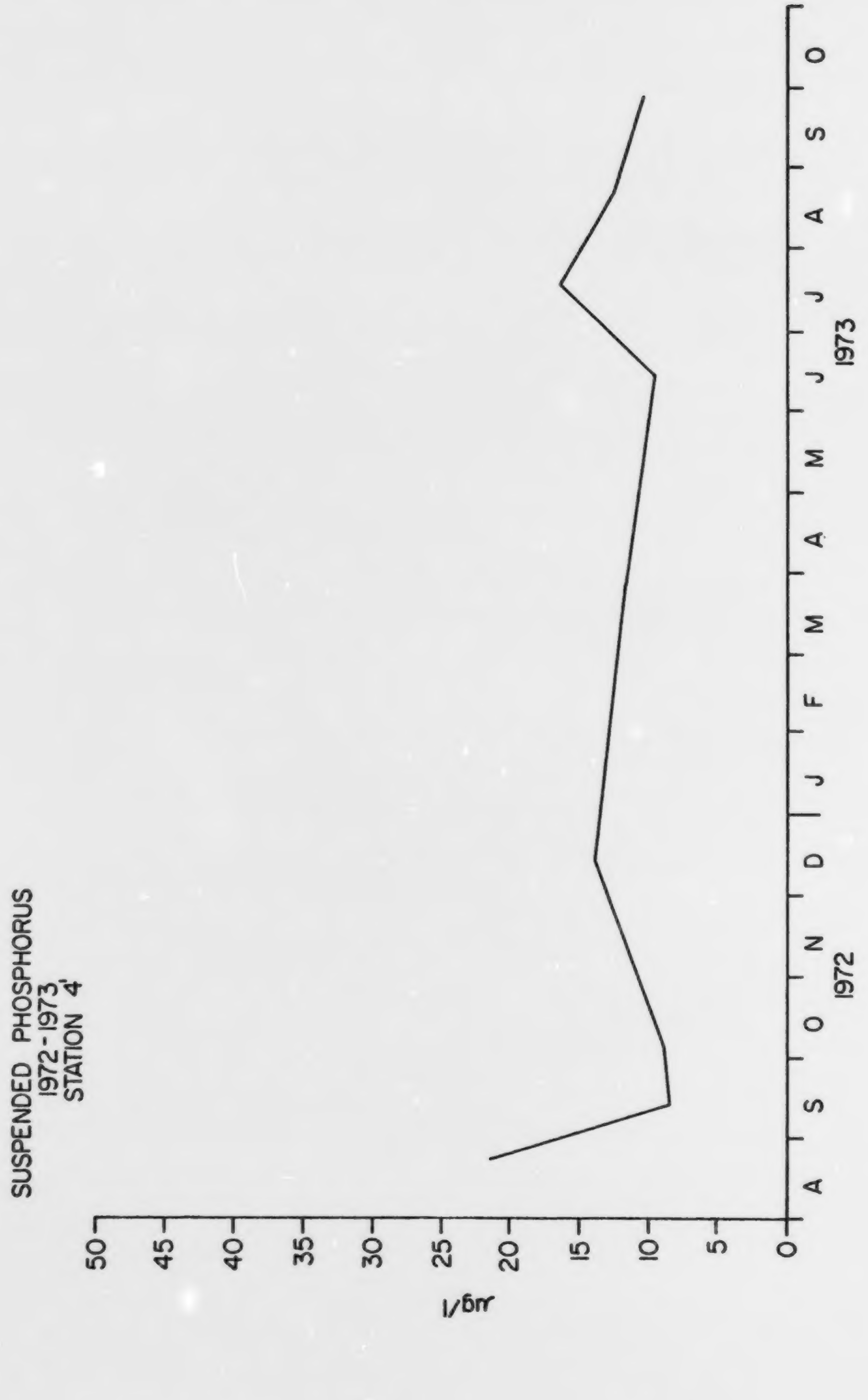




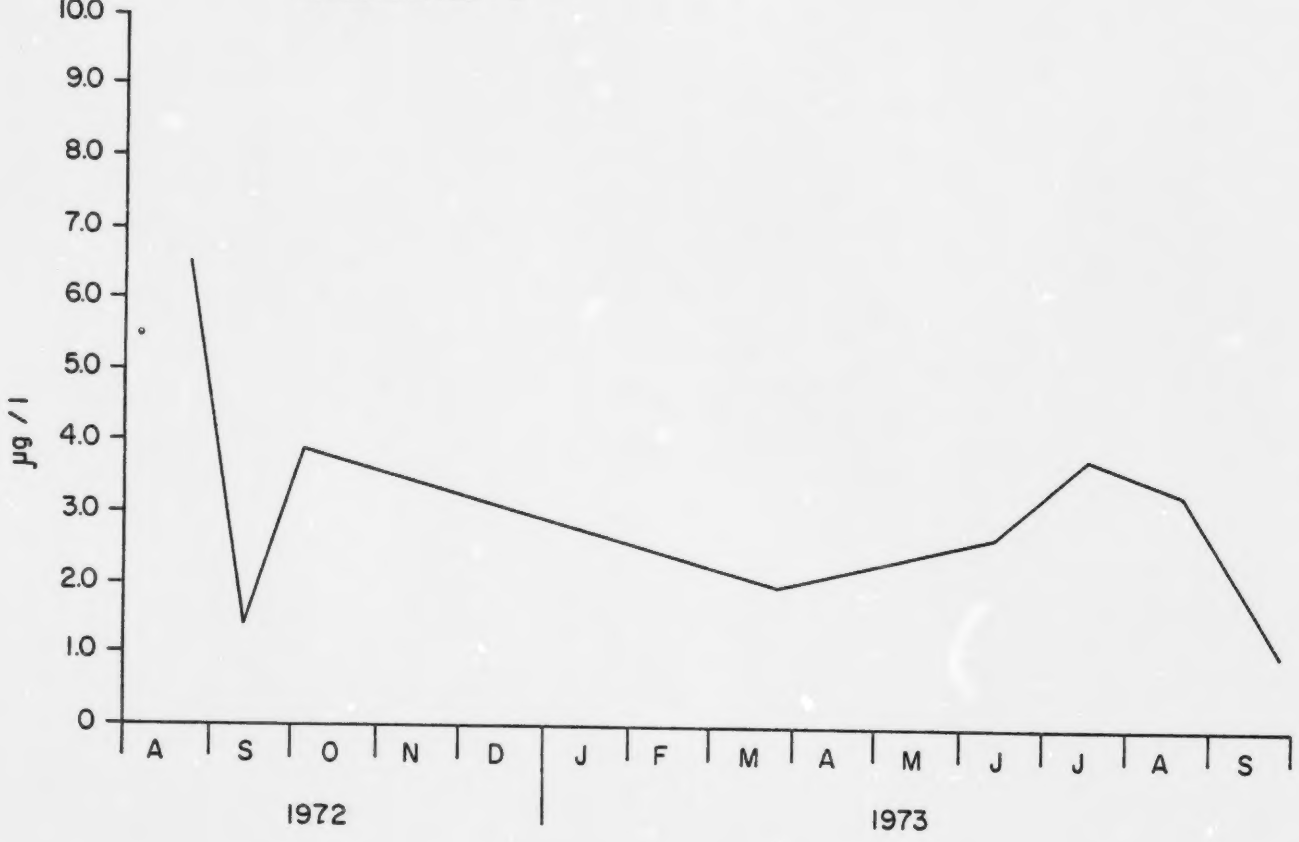
SUSPENDED PHOSPHORUS
1972-1973
STATION 2

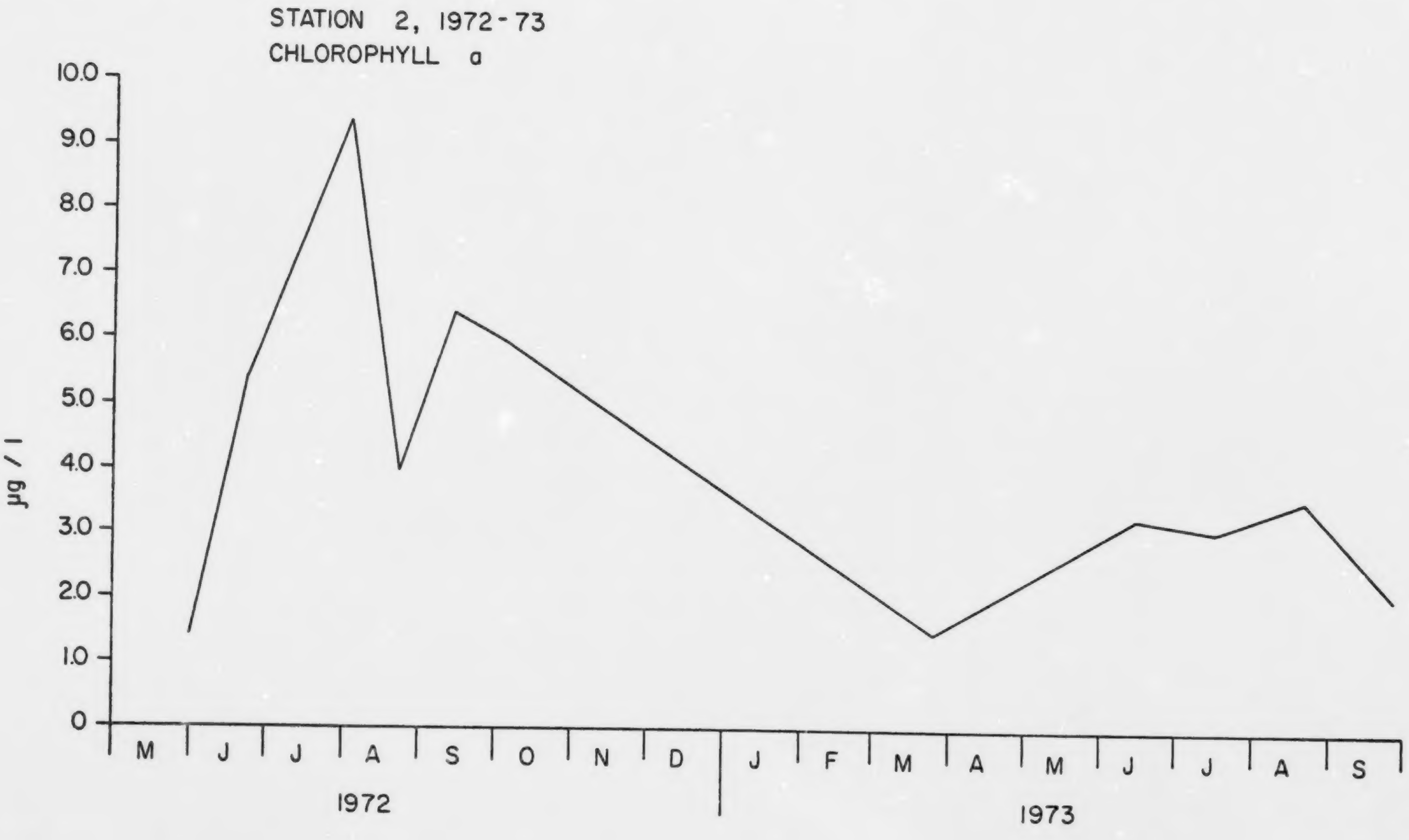


SUSPENDED PHOSPHORUS
1972 - 1973
STATION 4


SUSPENDED PHOSPHORUS
1972-1973
STATION 4'
µg/l
0
5
10
15
20
25
30
35
40
45
50
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

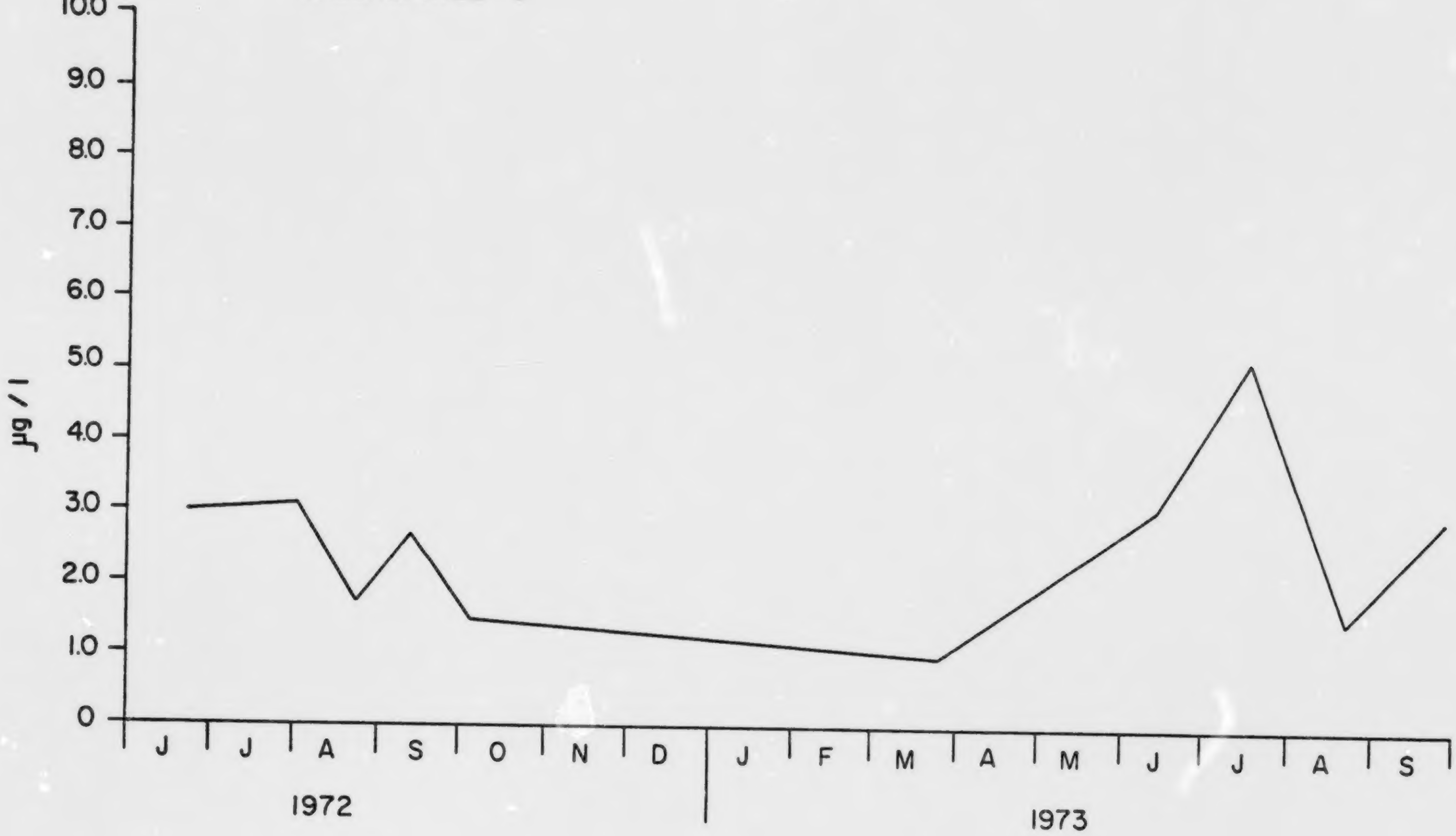
STATION 200, 1972-73
CHLOROPHYLL a



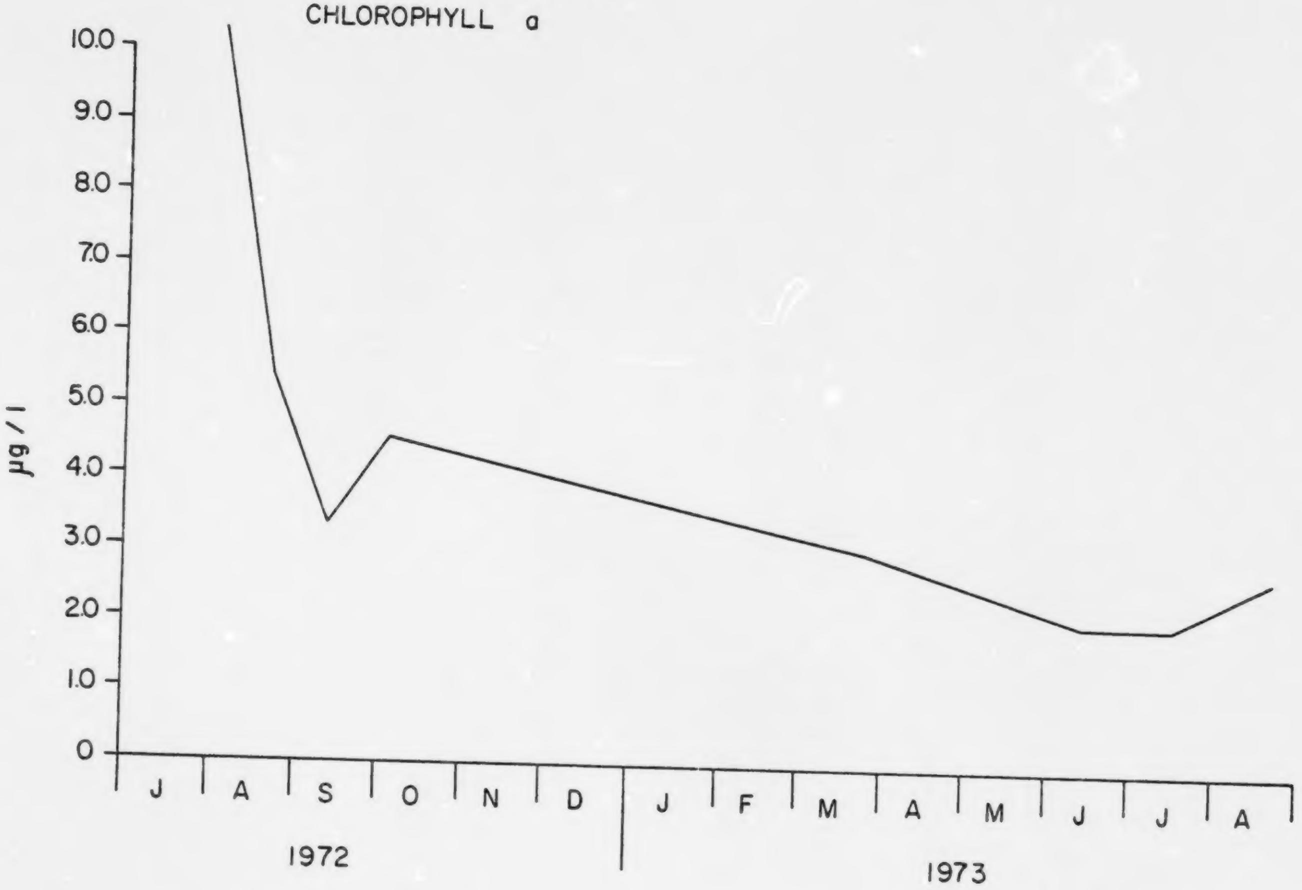


STATION 2, 1972-73
CHLOROPHYLL a

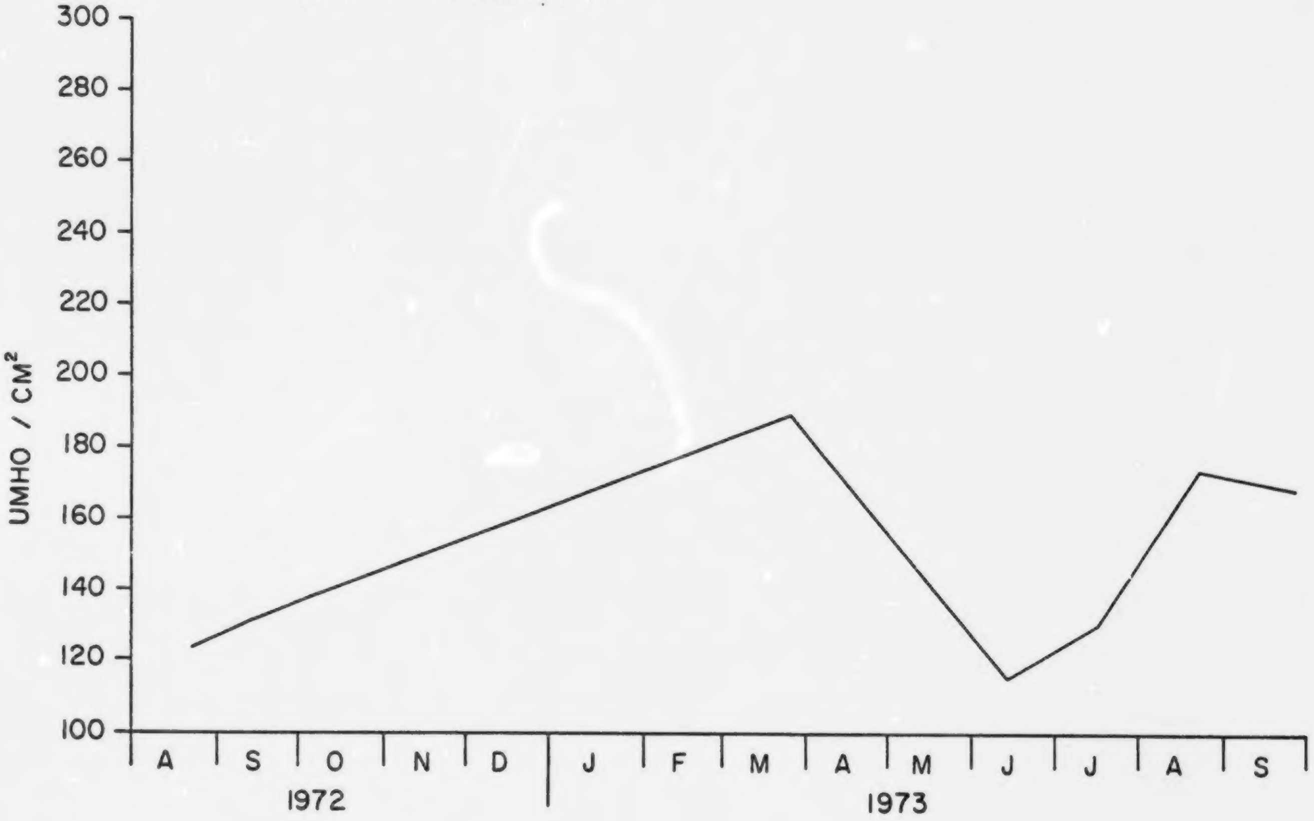
STATION 4, 1972-73
CHLOROPHYLL · a

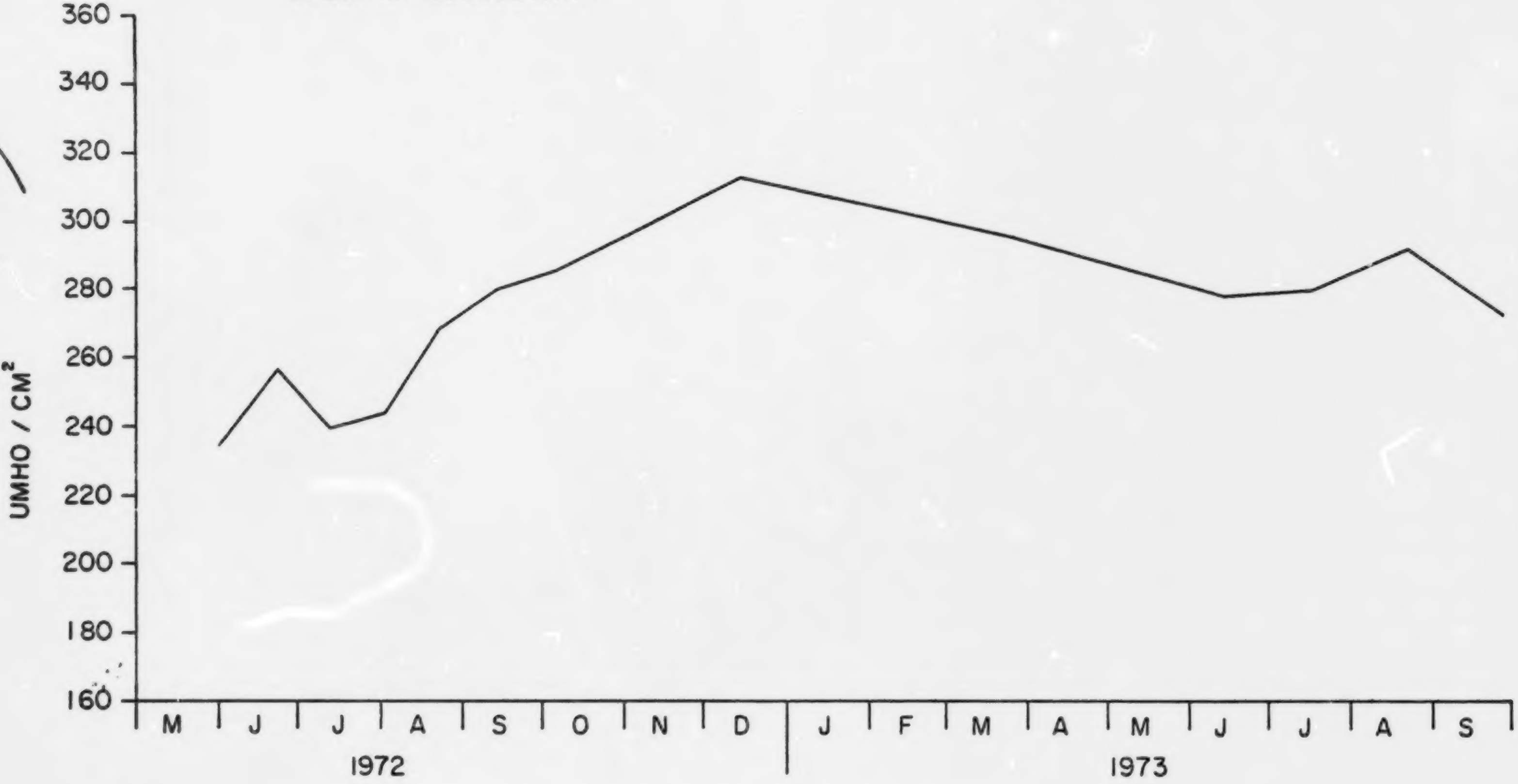


STATION 4', 1972-1973
CHLOROPHYLL a

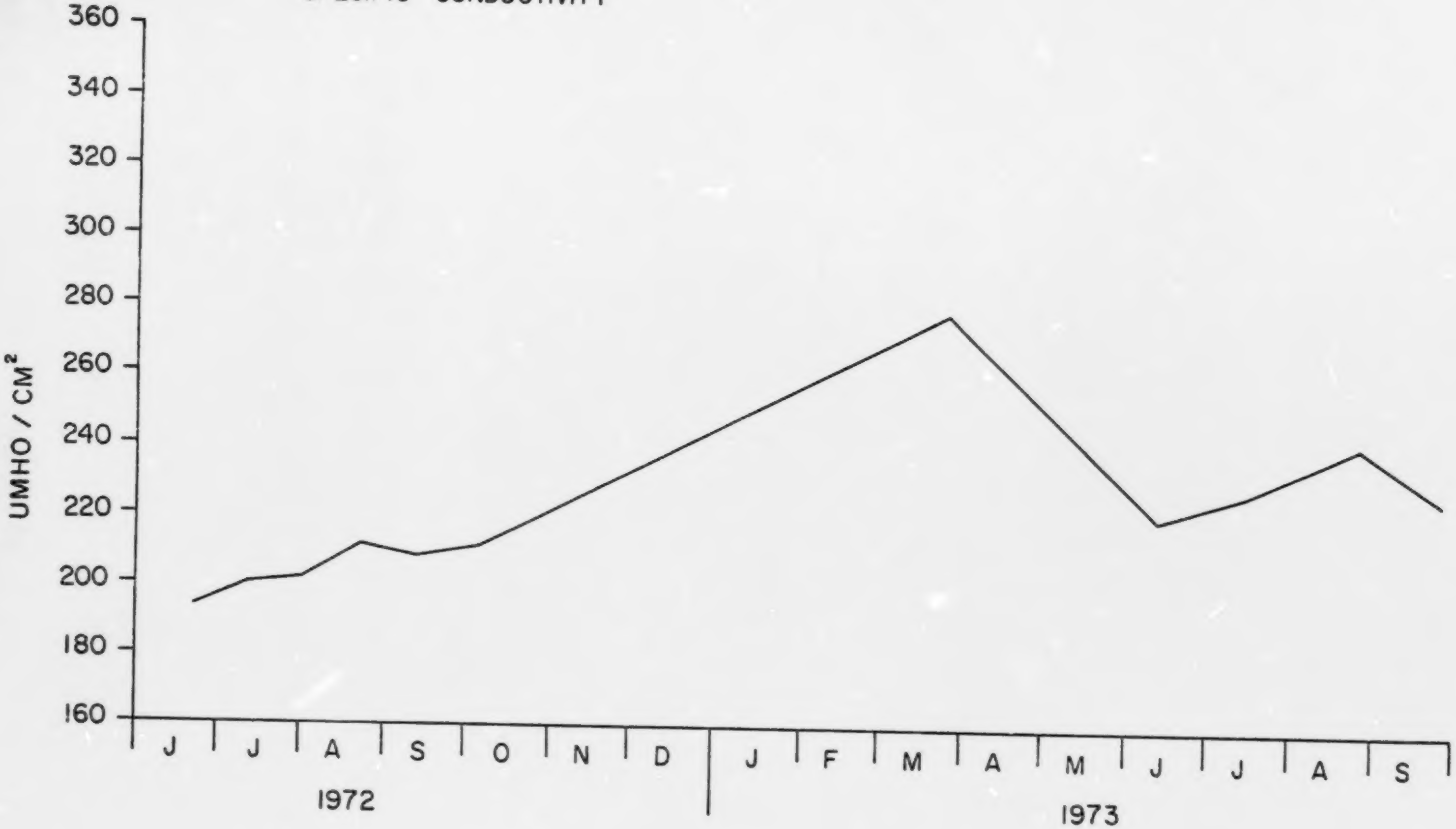


STATION 200, 1972-73
SPECIFIC CONDUCTIVITY

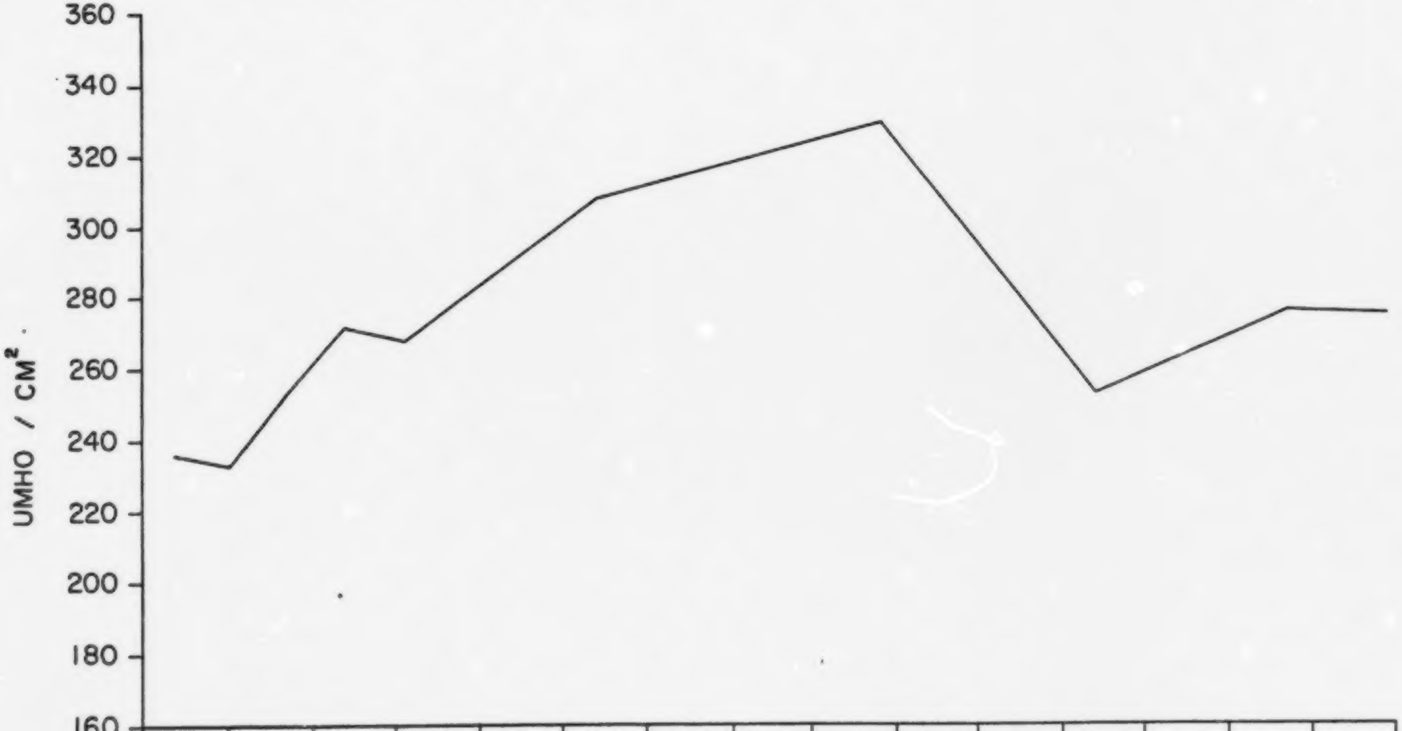




STATION 2, 1972-73
SPECIFIC CONDUCTIVITY

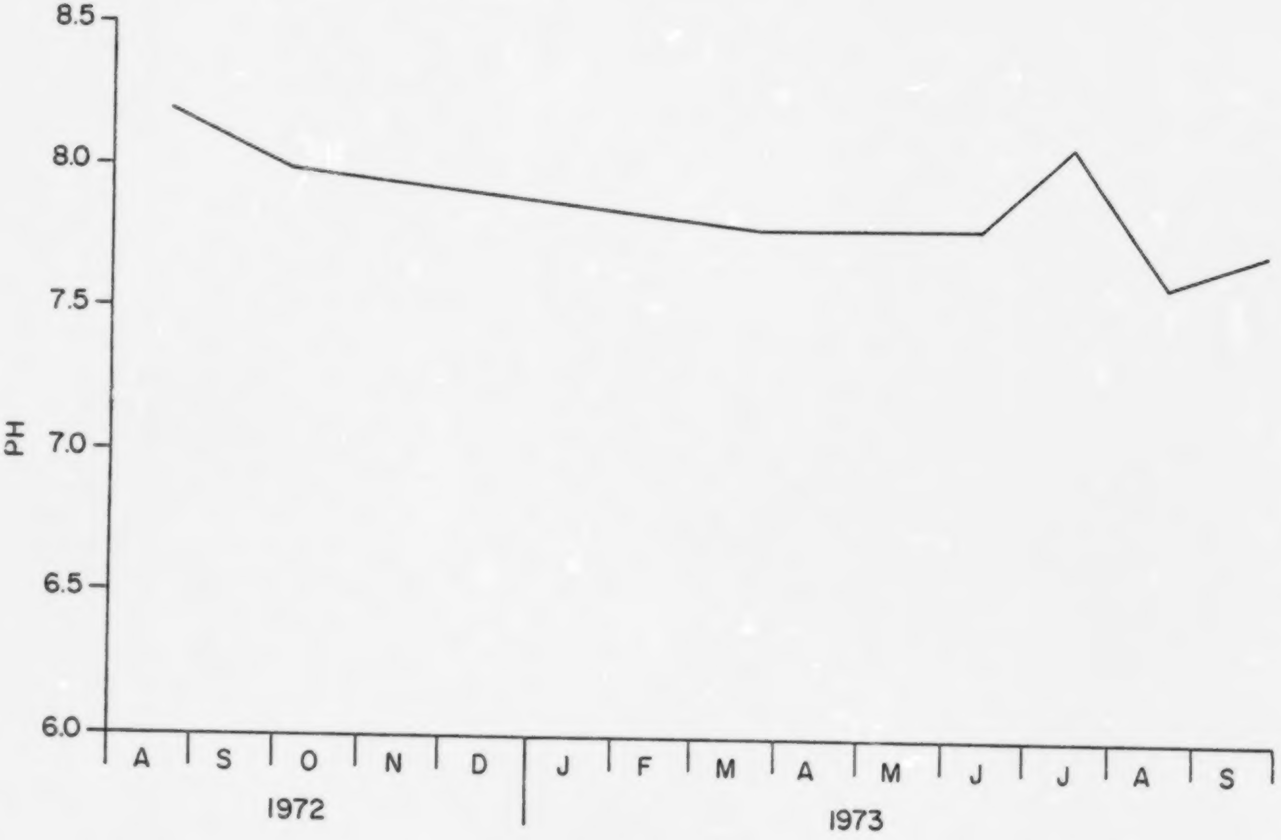

STATION 4, 1972-73
SPECIFIC CONDUCTIVITY

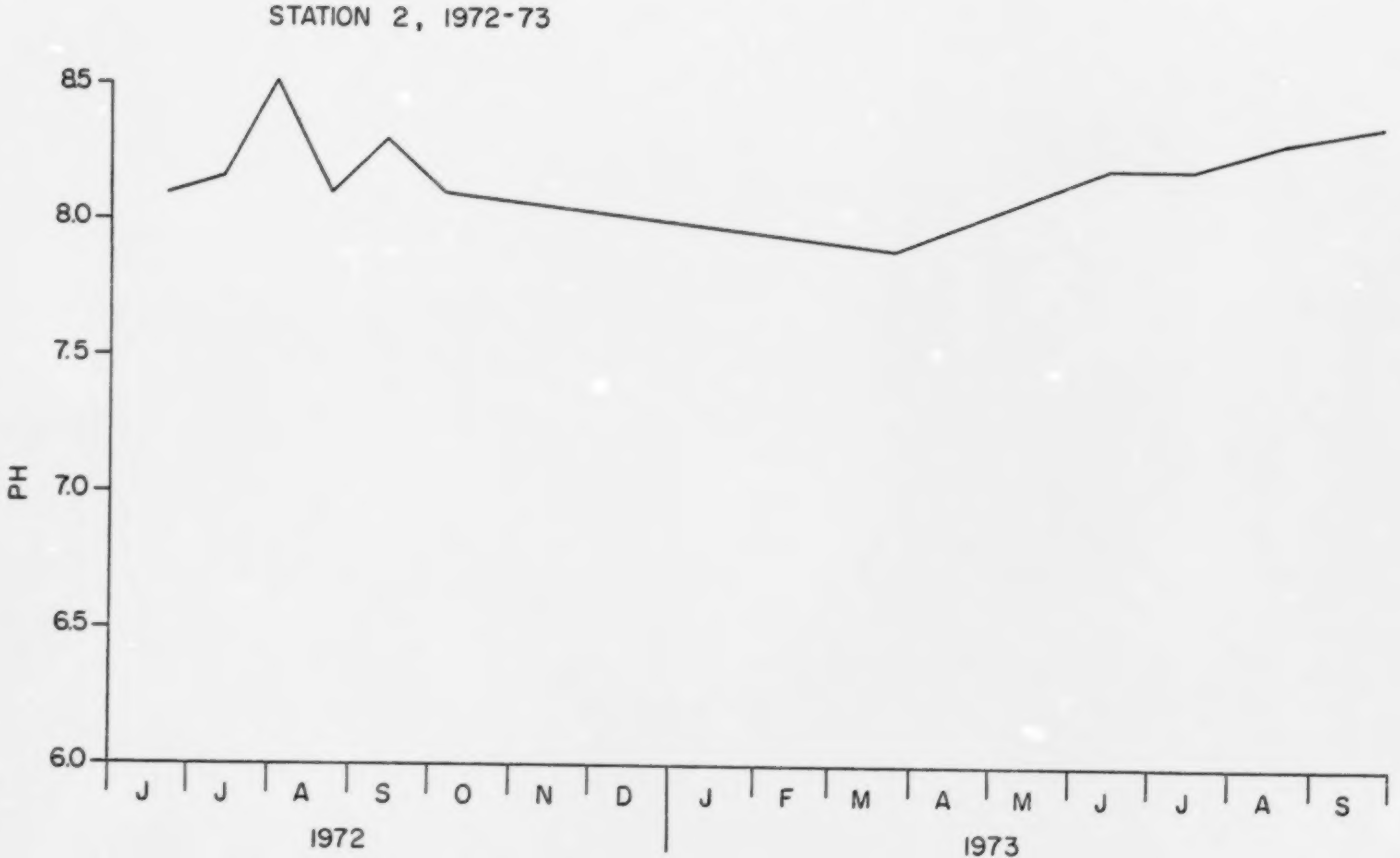
STATION 4', 1972-73
SPECIFIC CONDUCTIVITY



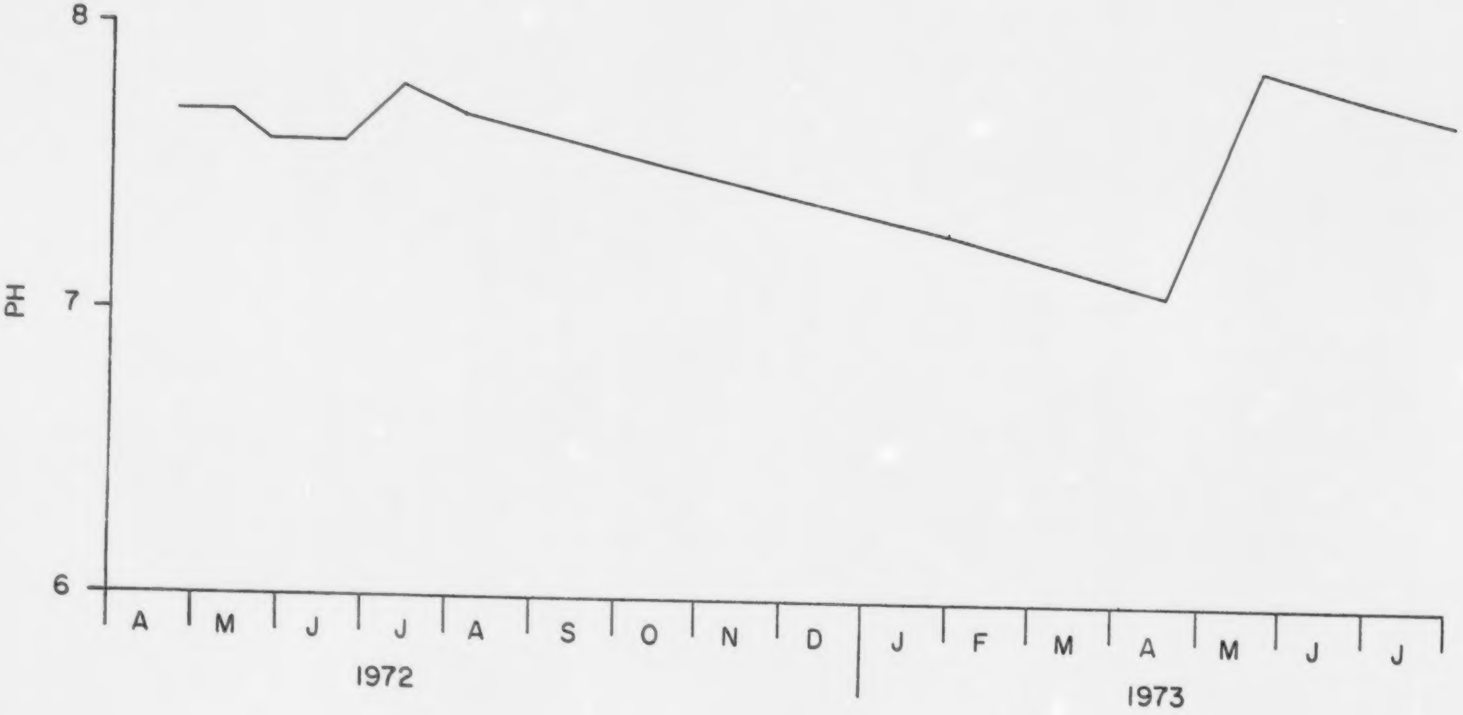
1972 1973

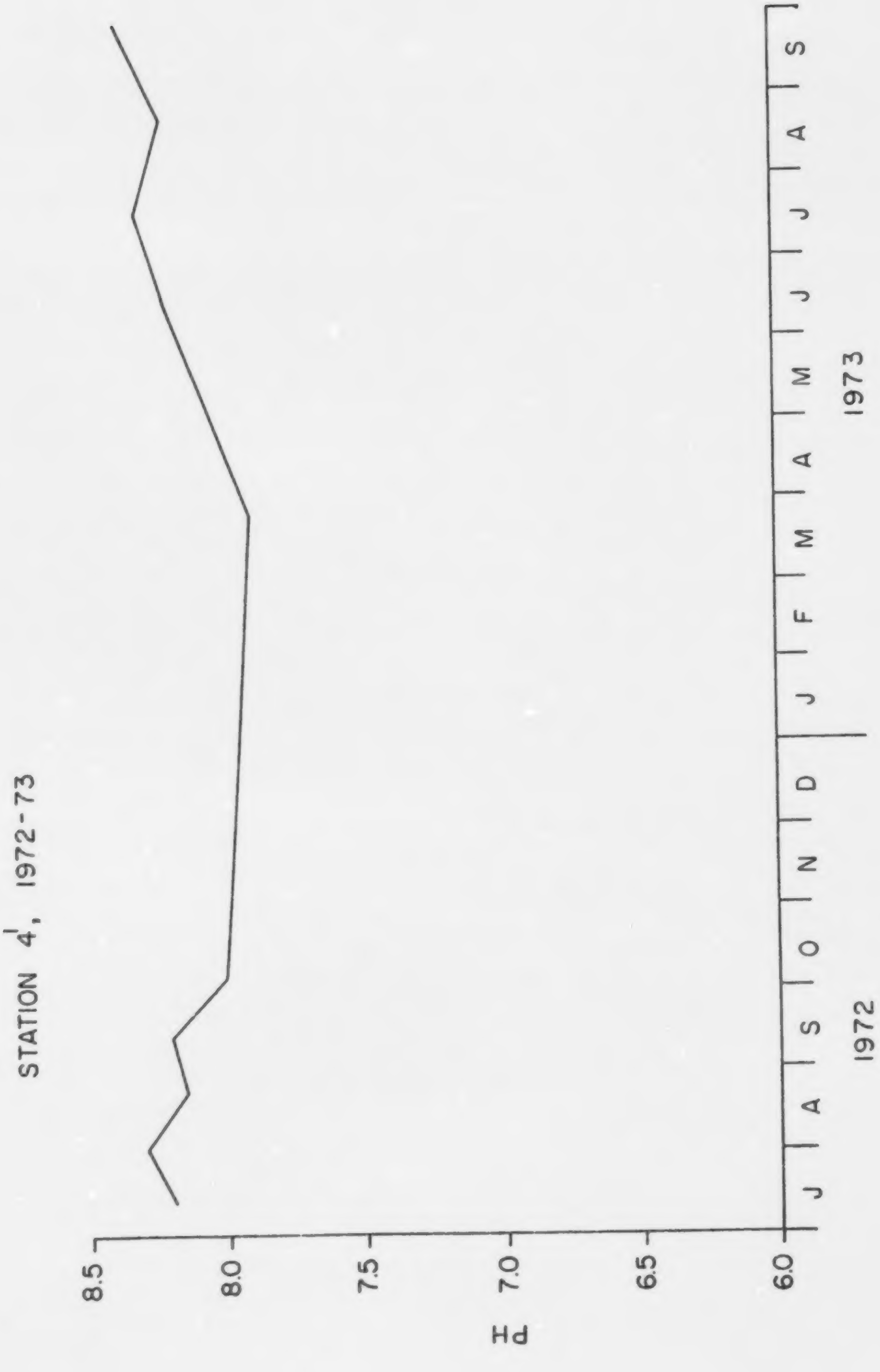
STATION 200, 1972-73

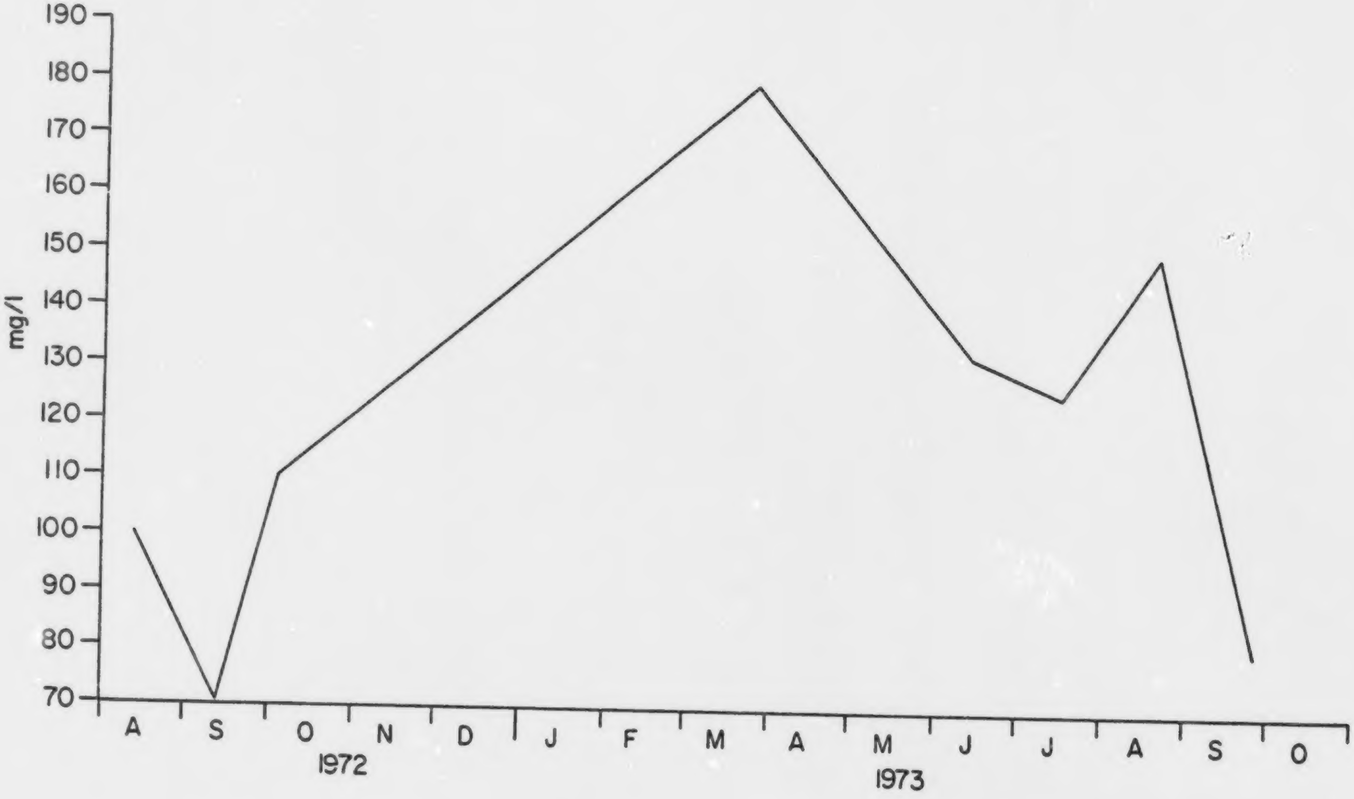



STATION 2, 1972-73

STATION 4, 1972-73

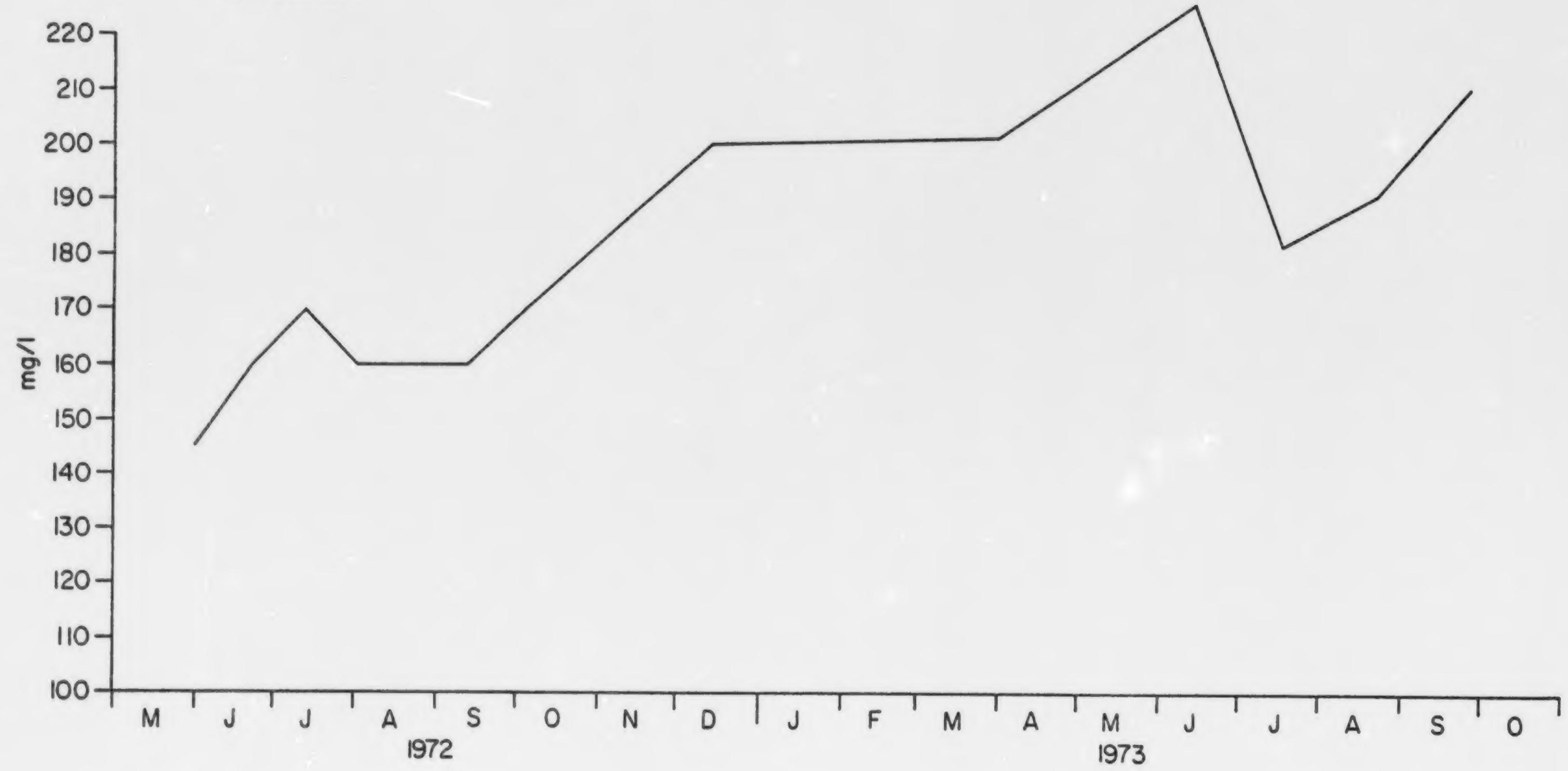


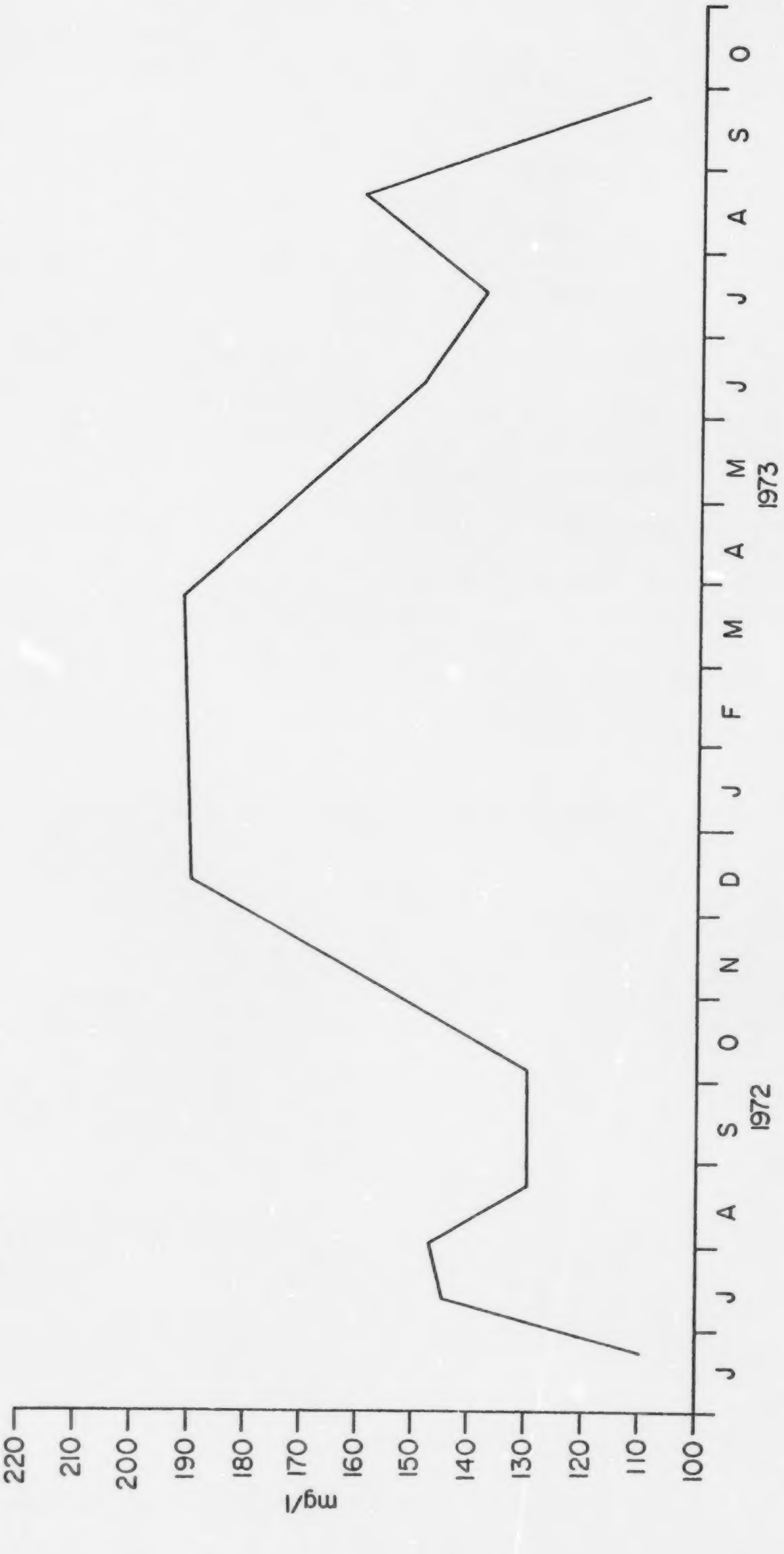

STATION 4', 1972-73
pH
8.5
8.0
7.5
7.0
6.5
6.0
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
1972
1973



TOTAL DISSOLVED SOLIDS
1972 - 1973
STATION 200

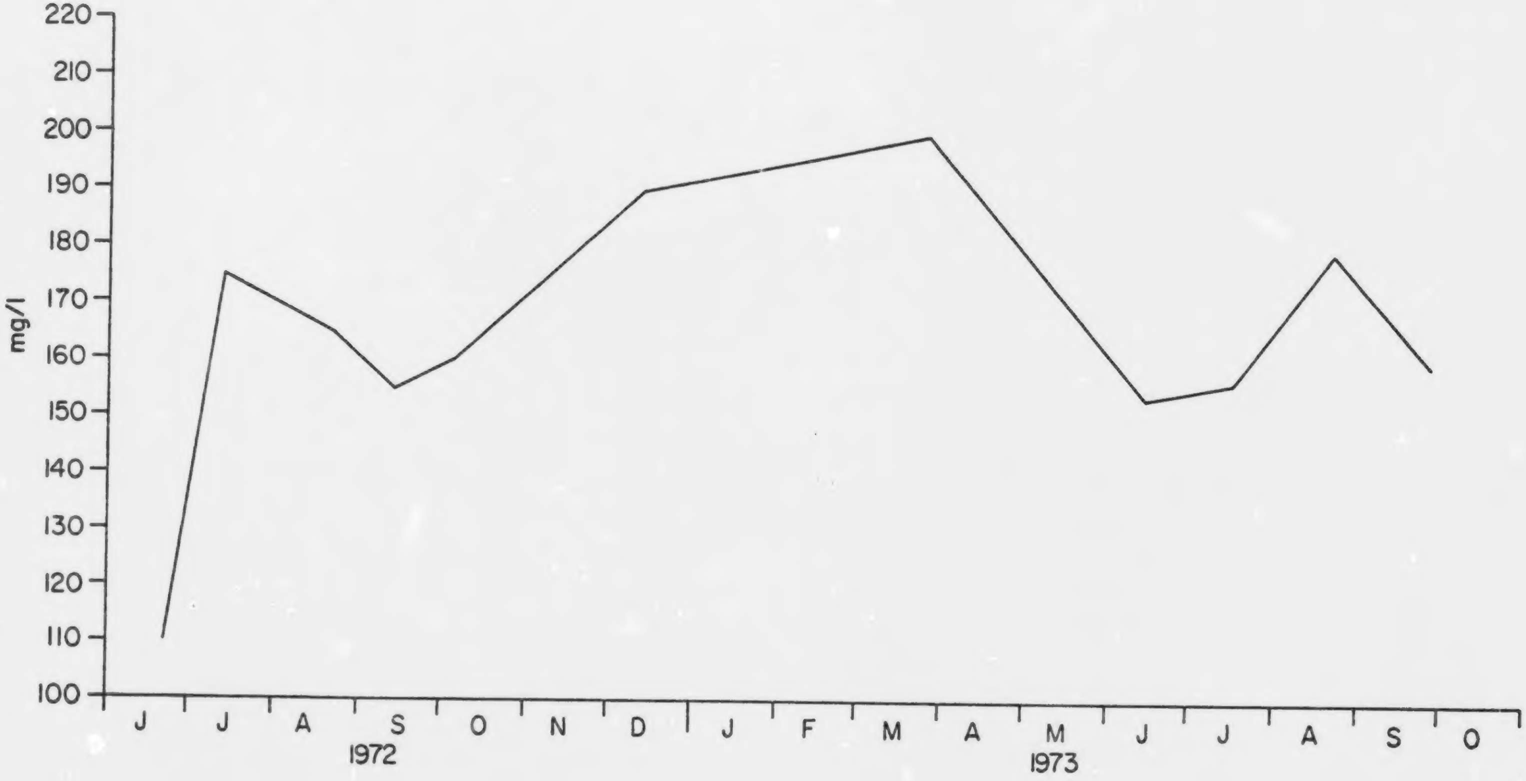
TOTAL DISSOLVED SOLIDS
1972 - 1973
STATION 2



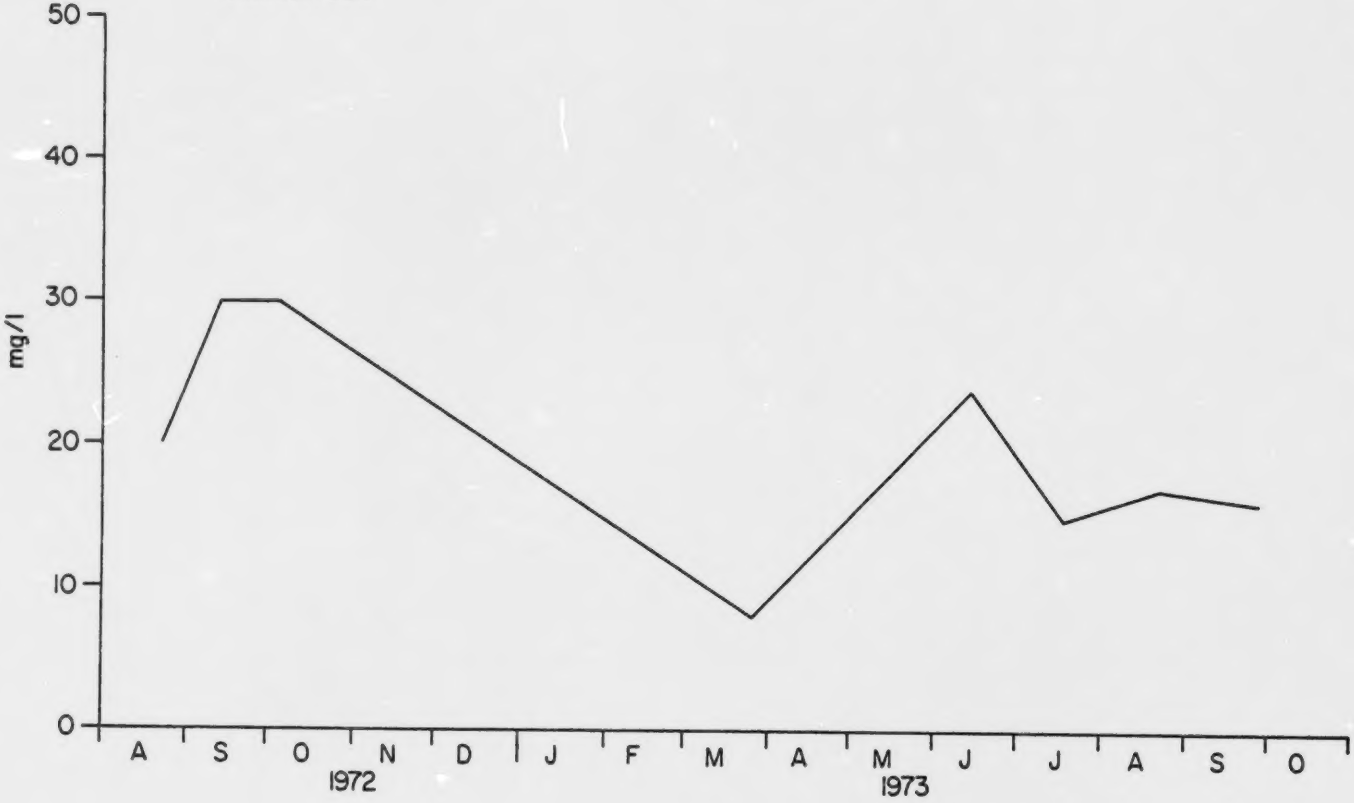


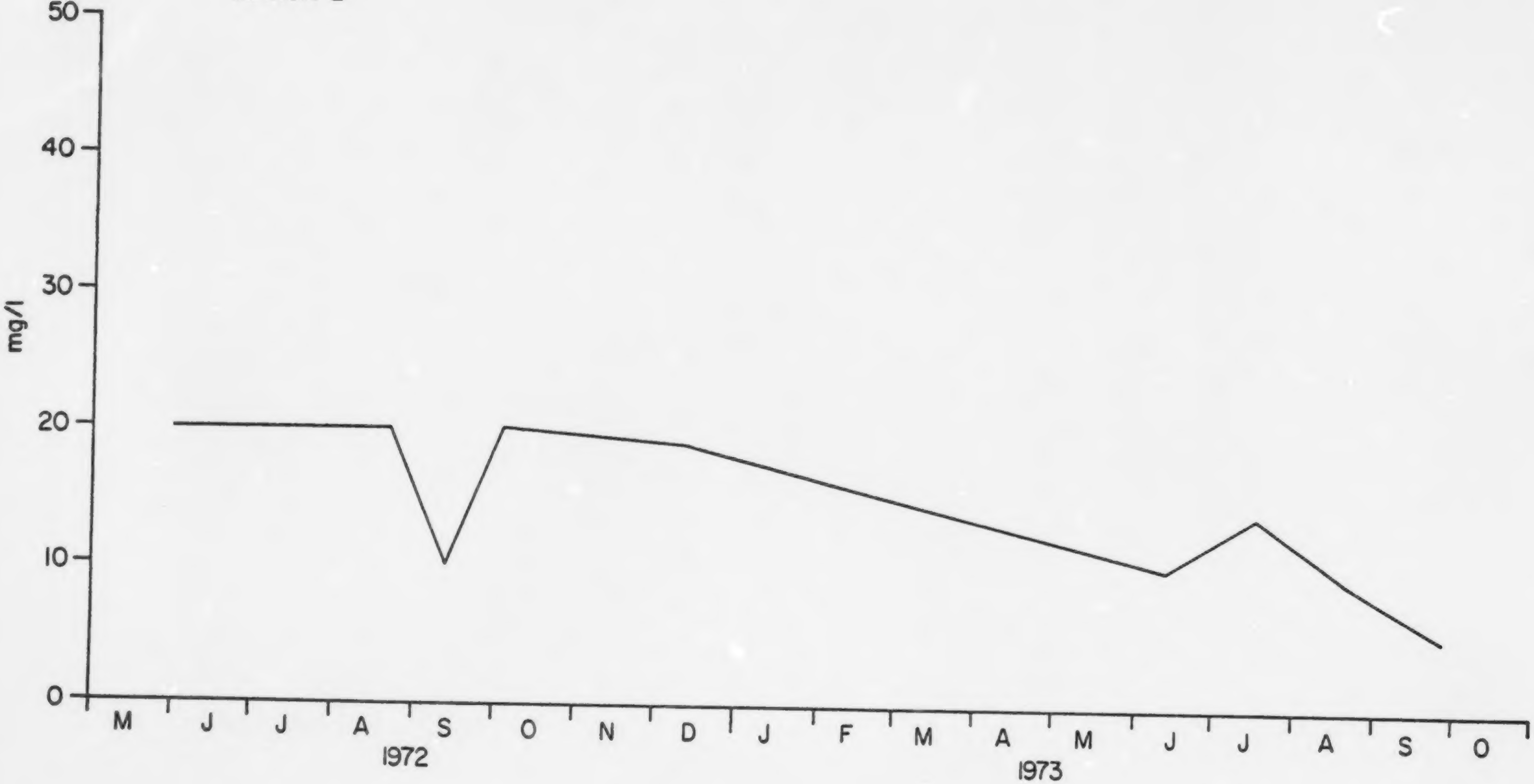
TOTAL DISSOLVED SOLIDS
1972 - 1973
STATION 4

TOTAL DISSOLVED SOLIDS
1972-1973
STATION 4'



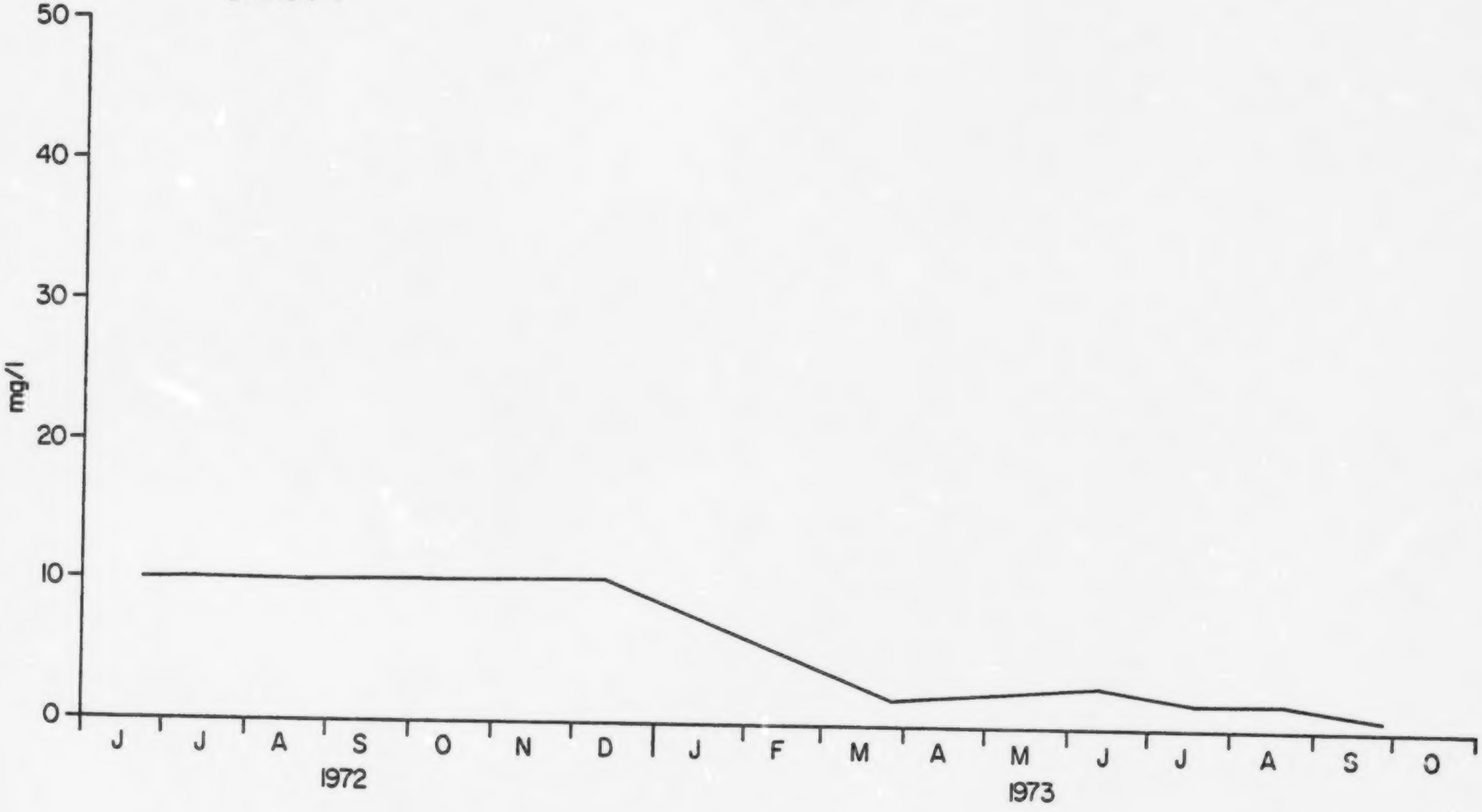
TOTAL SUSPENDED SOLIDS
1972-1973
STATION 200

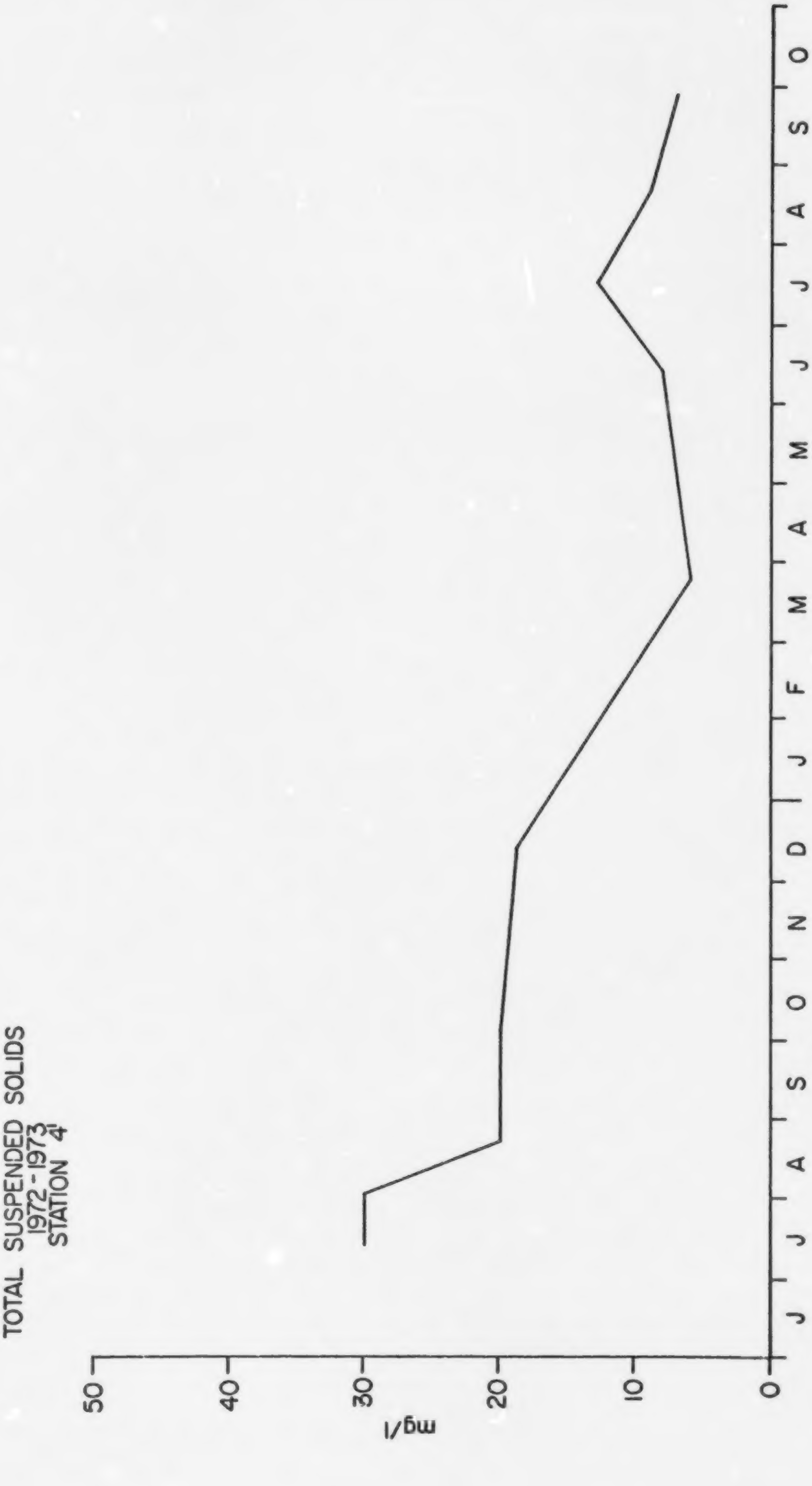




TOTAL SUSPENDED SOLIDS
1972 - 1973
STATION 2

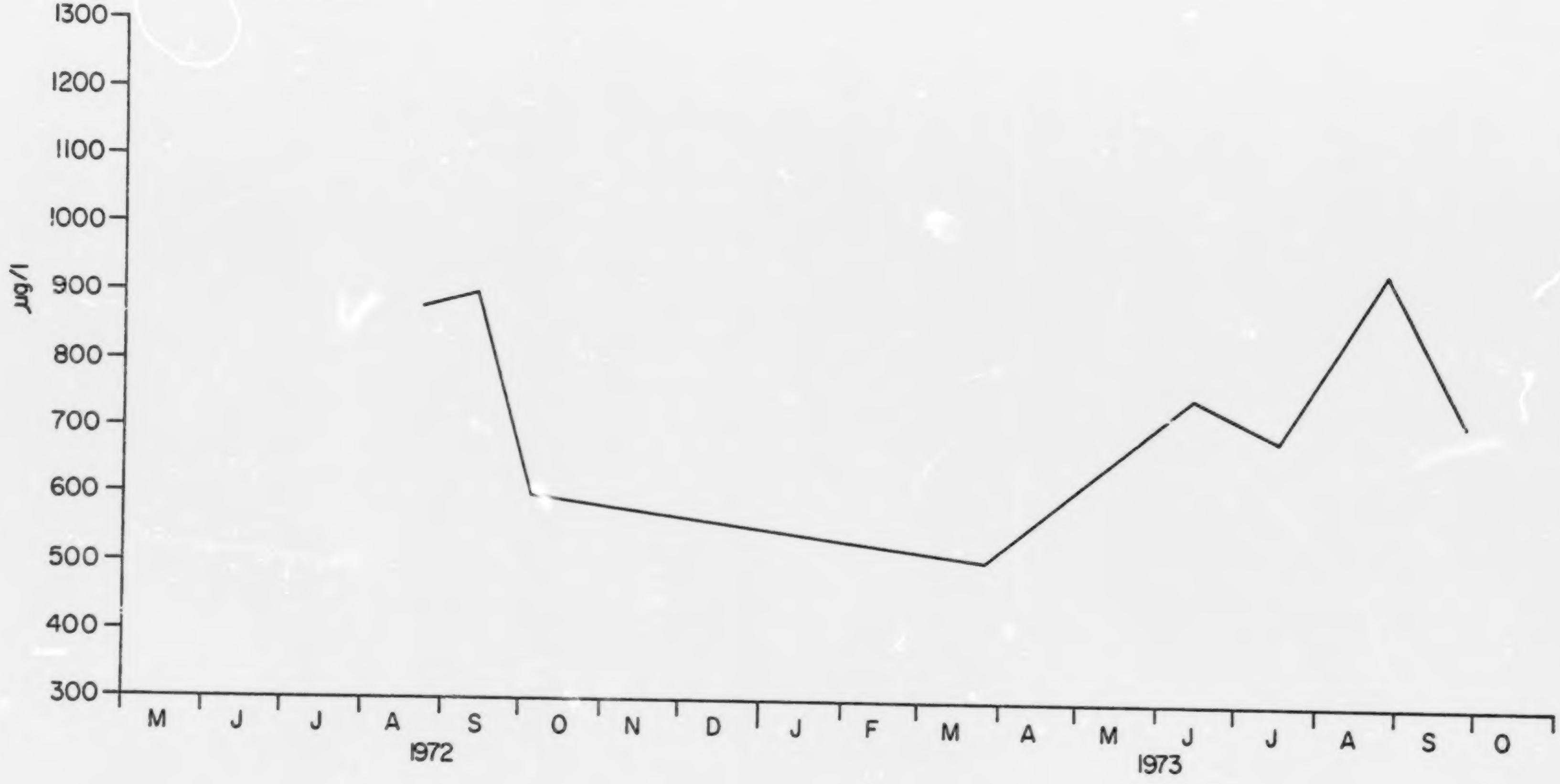
TOTAL SUSPENDED SOLIDS
1972 - 1973
STATION 4

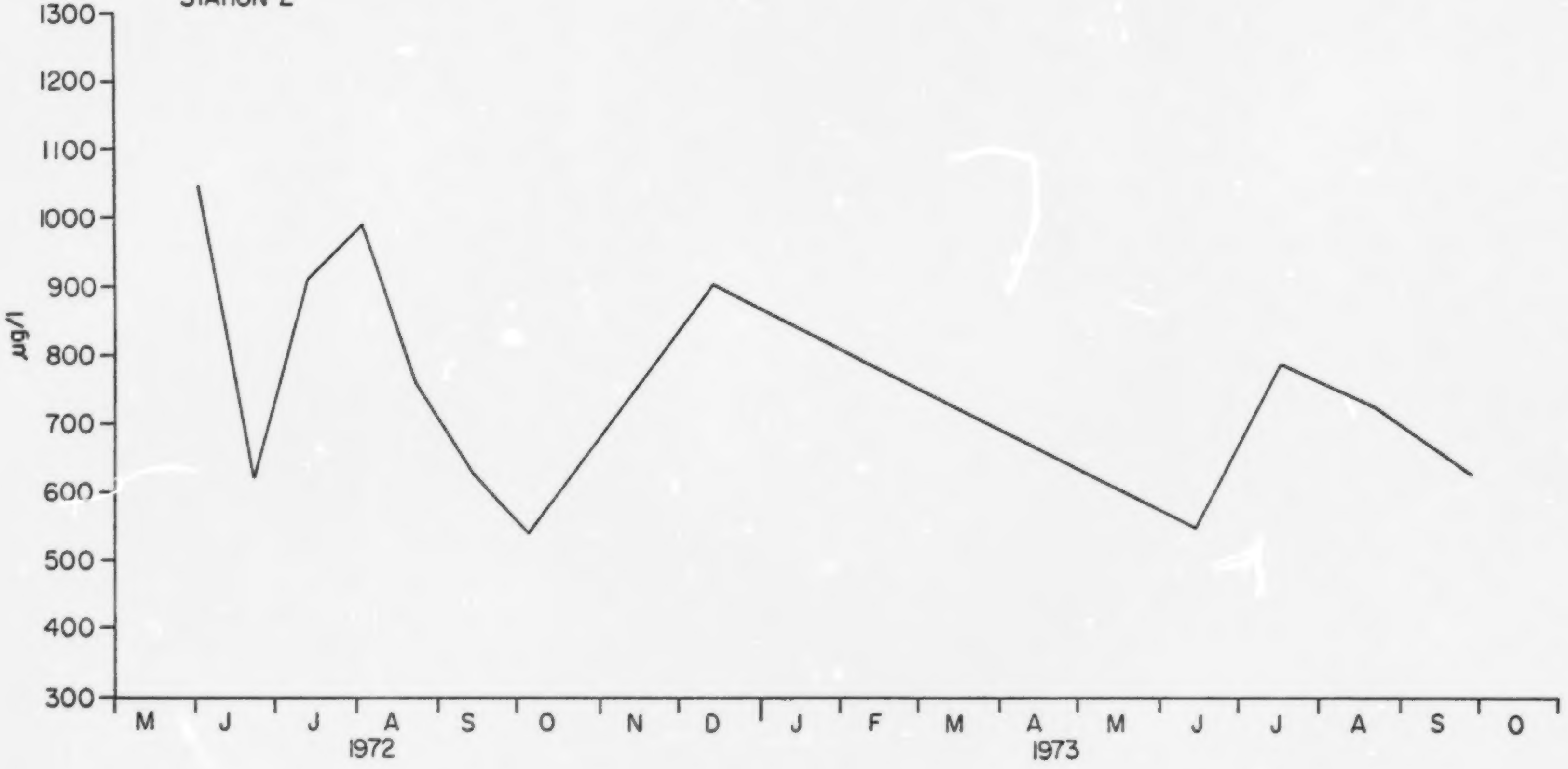




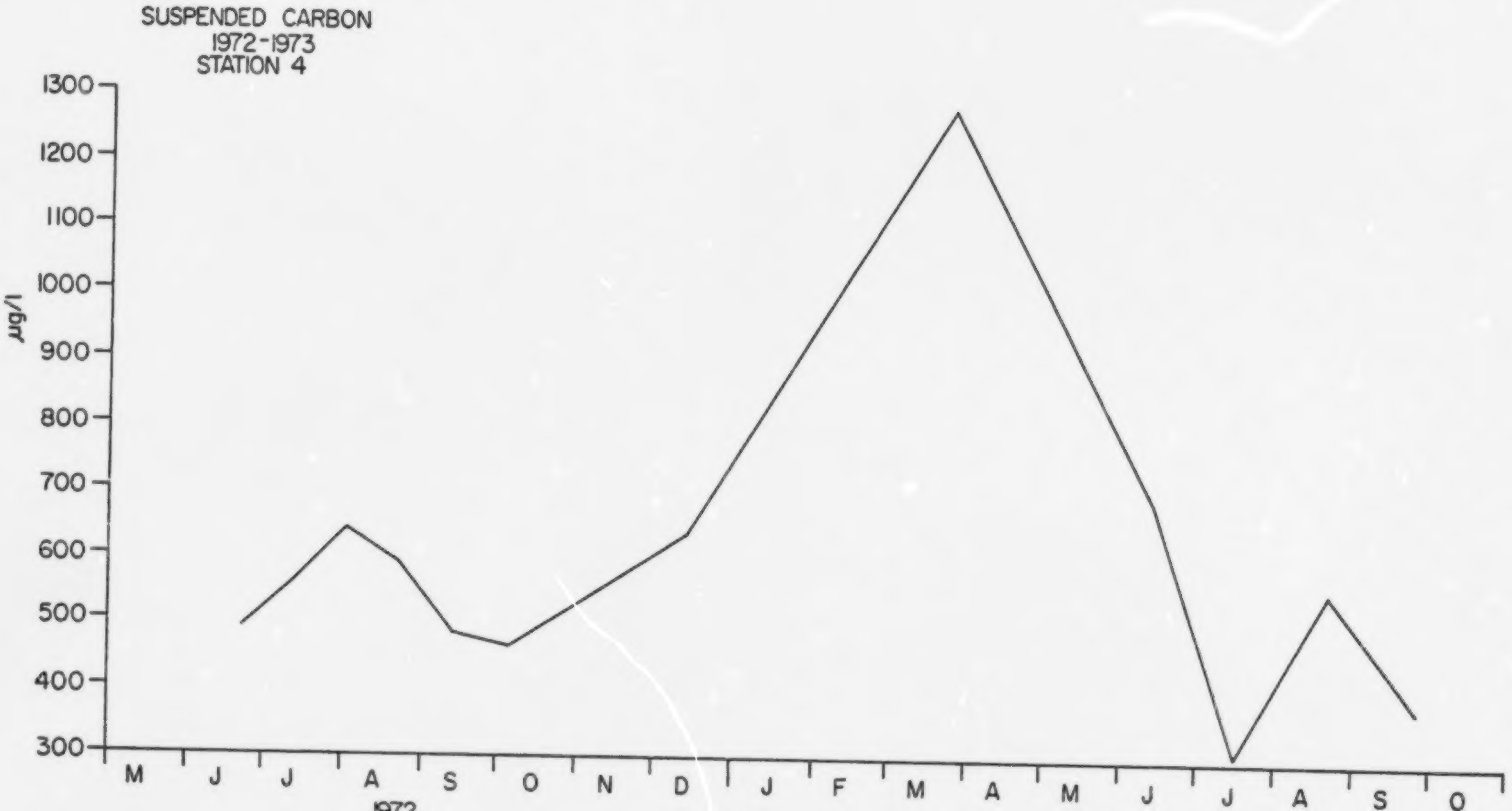
TOTAL SUSPENDED SOLIDS
1972 - 1973
STATION 4
mg/l
0
10
20
30
40
50
J
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

SUSPENDED CARBON
1972-1973
STATION 200

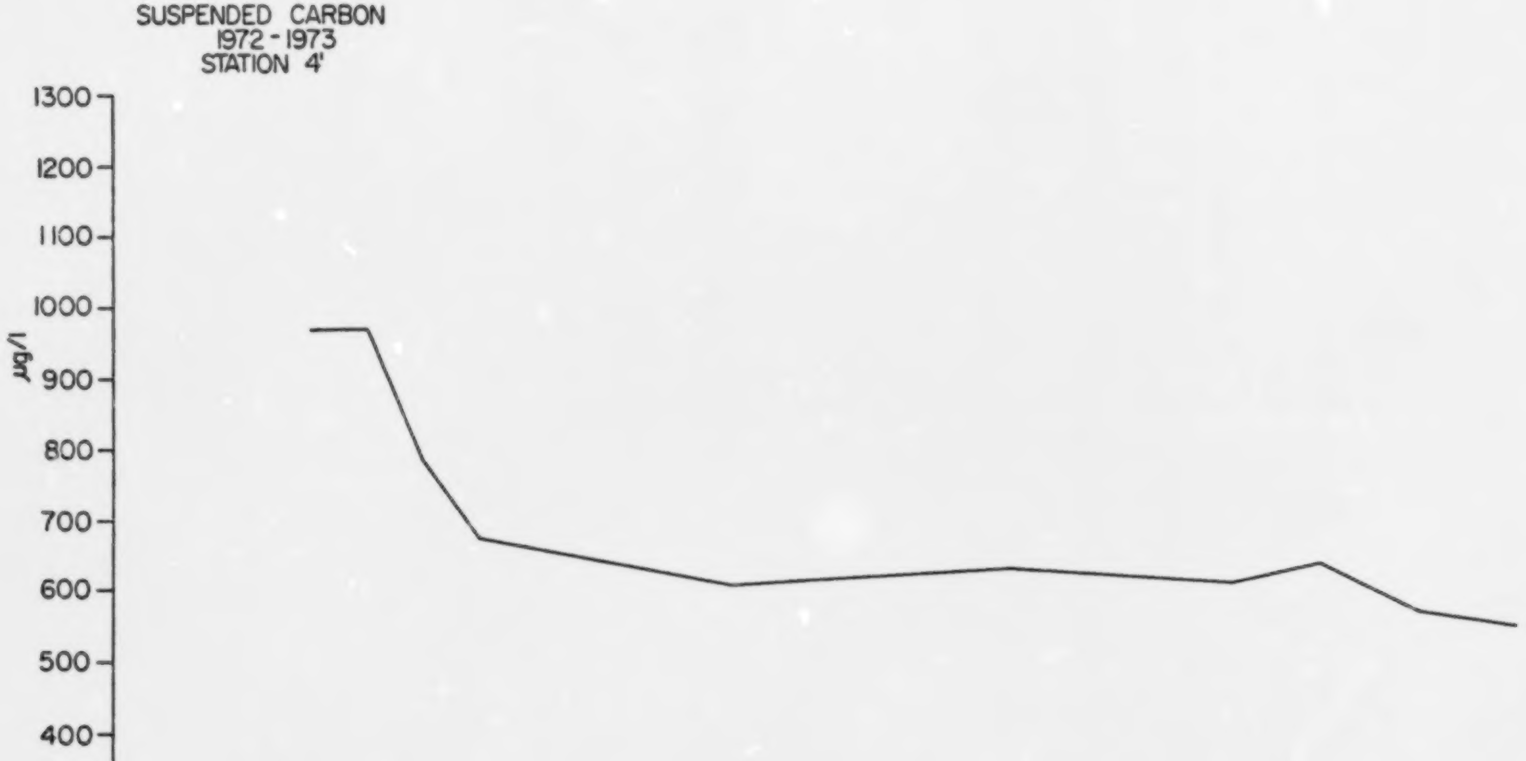




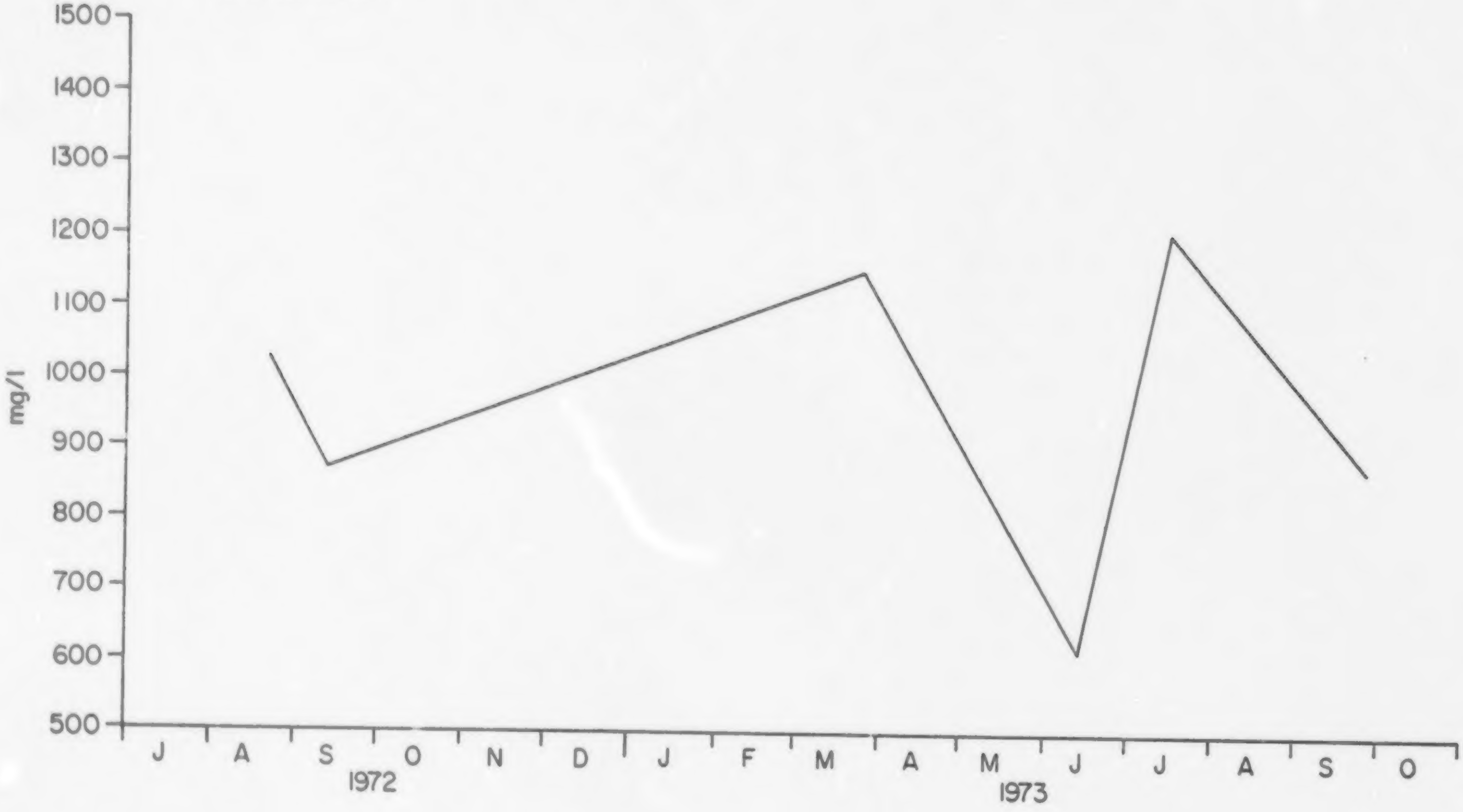
SUSPENDED CARBON
1972-1973
STATION 2

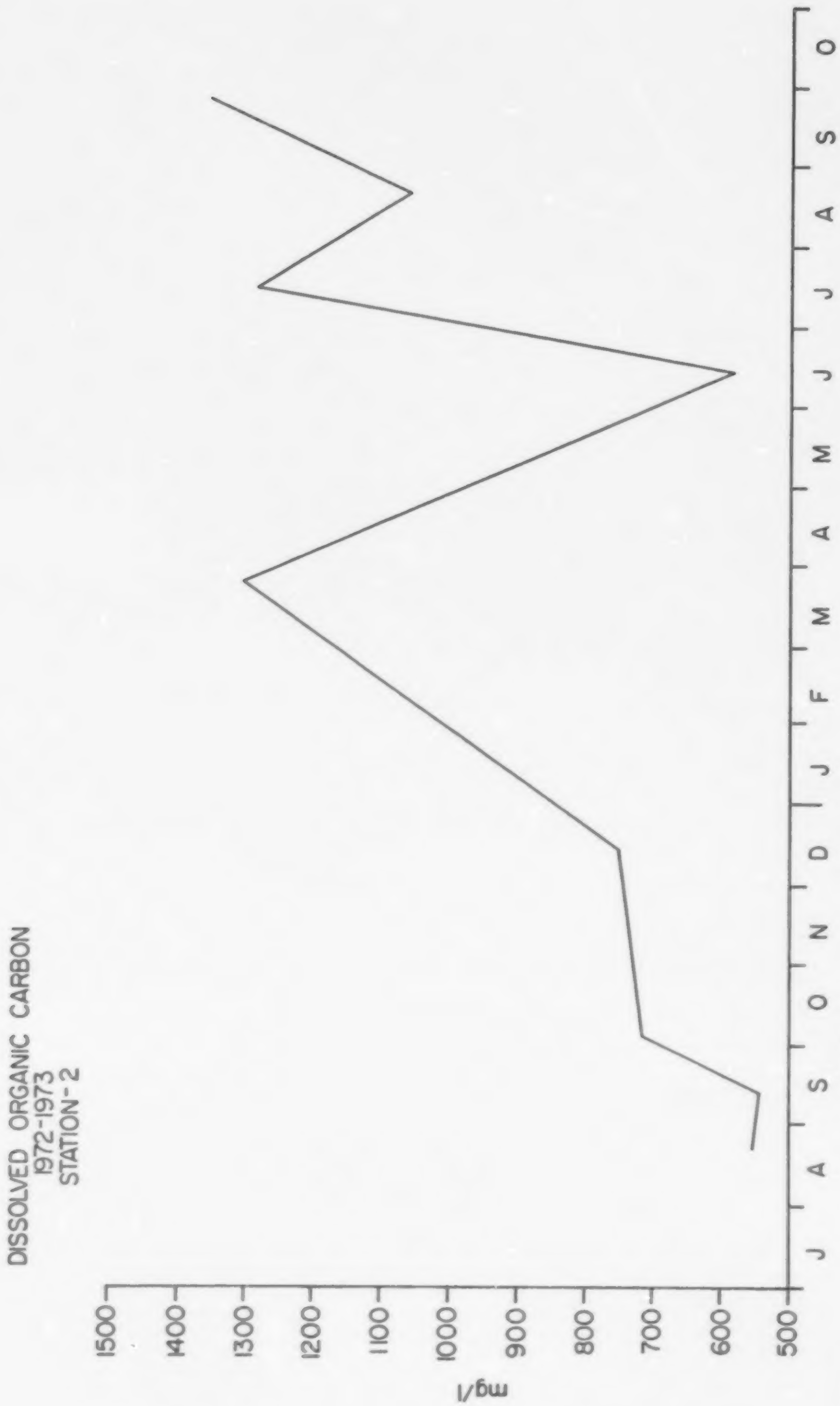


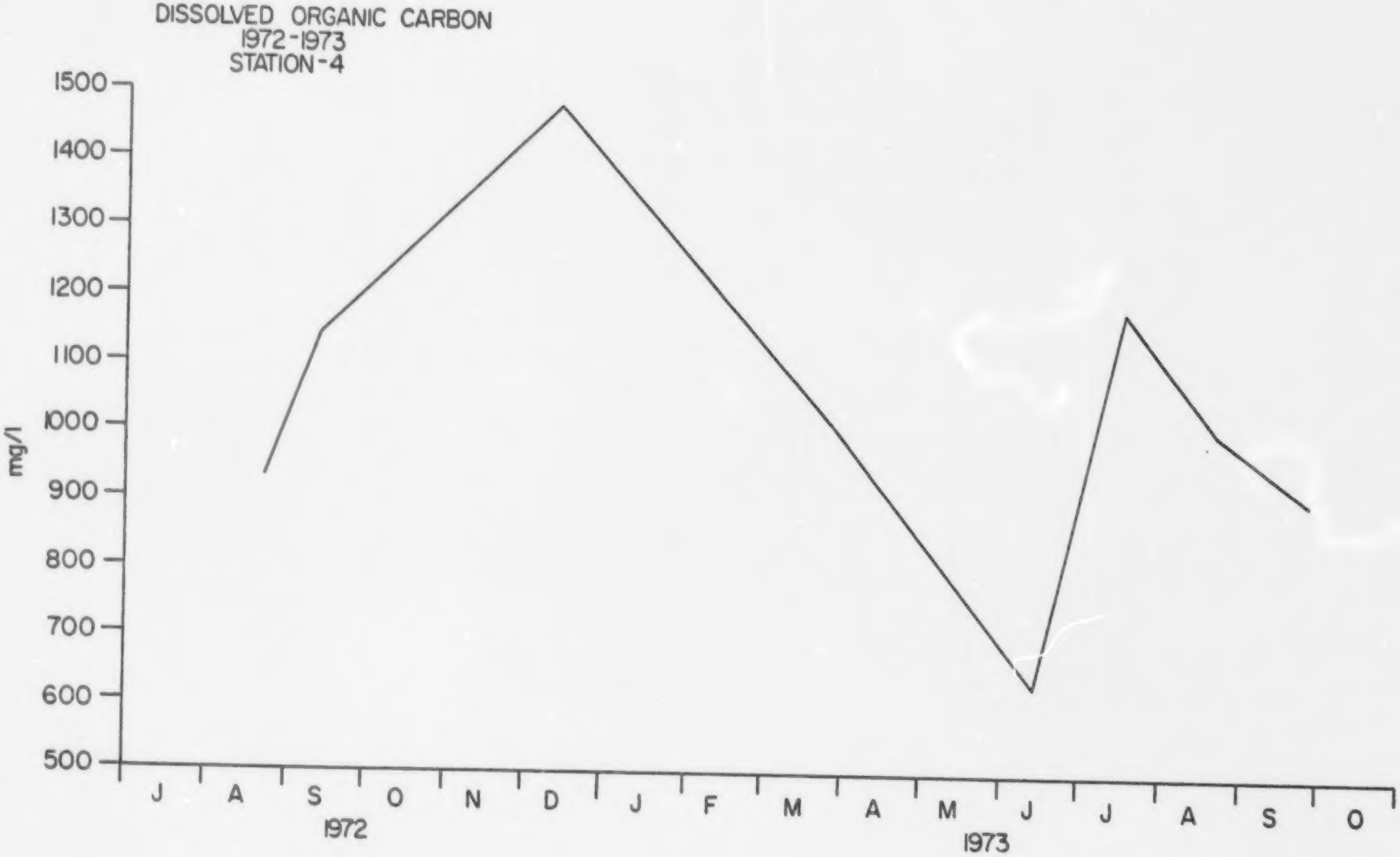
SUSPENDED CARBON
1972-1973
STATION 4

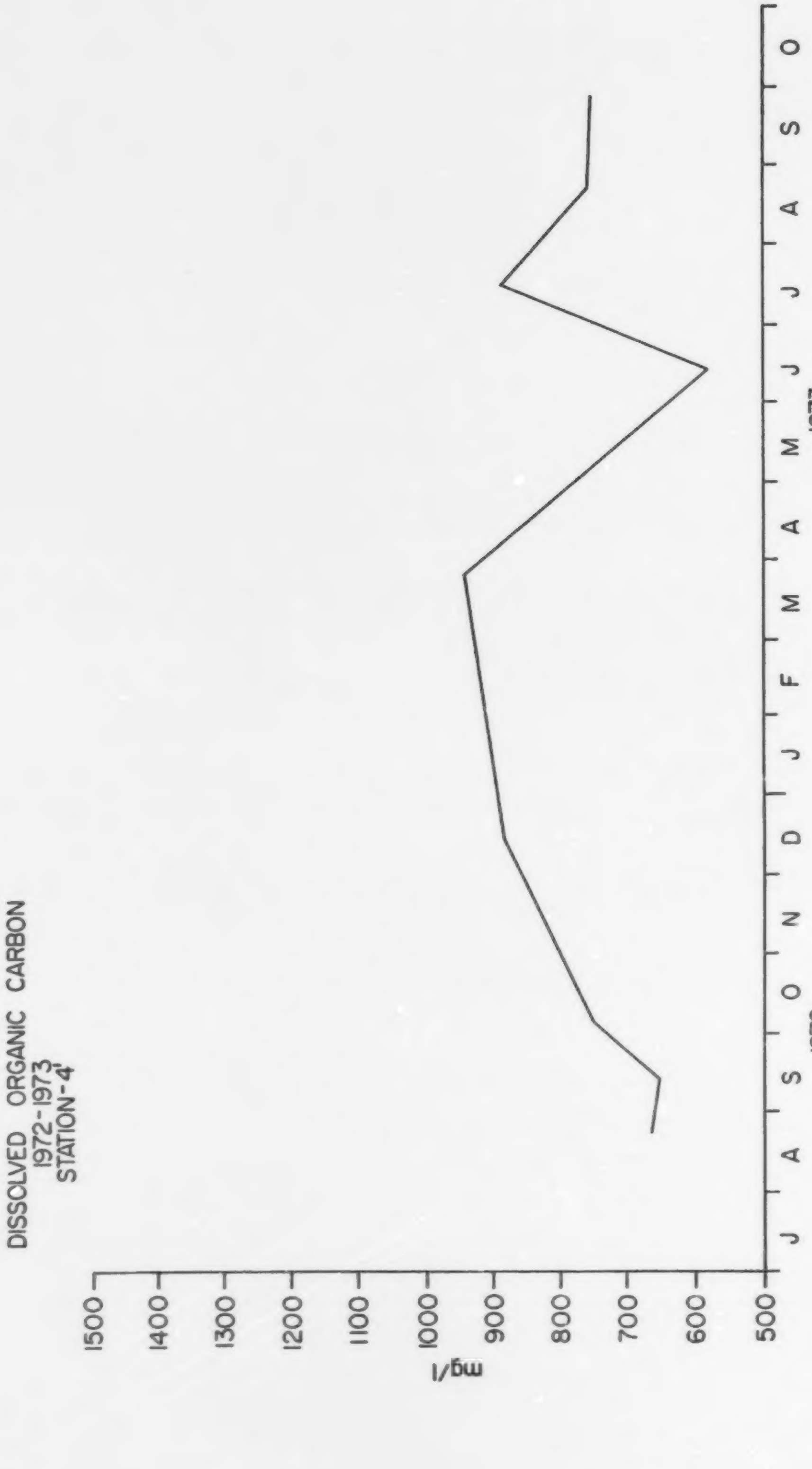

SUSPENDED CARBON
1972 - 1973
STATION 4'
µg/l
1300
1200
1100
1000
900
800
700
600
500
400

DISSOLVED ORGANIC CARBON
1972-1973
STATION 200




DISSOLVED ORGANIC CARBON
1972-1973
STATION-2
mg/l
1500
1400
1300
1200
1100
1000
900
800
700
600
500
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973

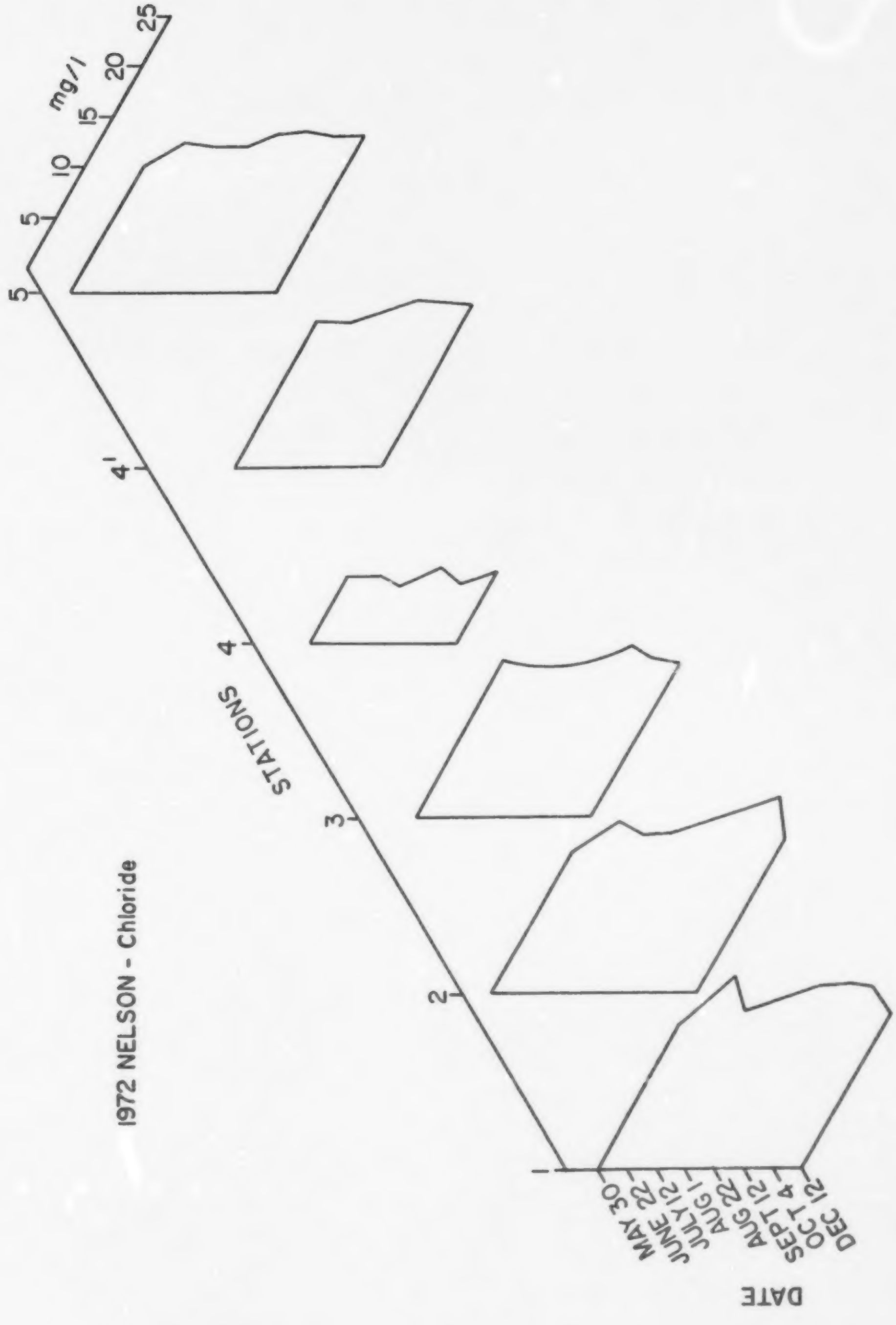

DISSOLVED ORGANIC CARBON
1972-1973
STATION-4
mg/l
1500
1400
1300
1200
1100
1000
900
800
700
600
500
J
A
S
O
N
D
J
F
M
A
M
J
J
A
S
O
1972
1973



DISSOLVED ORGANIC CARBON
1972-1973
STATION-4'

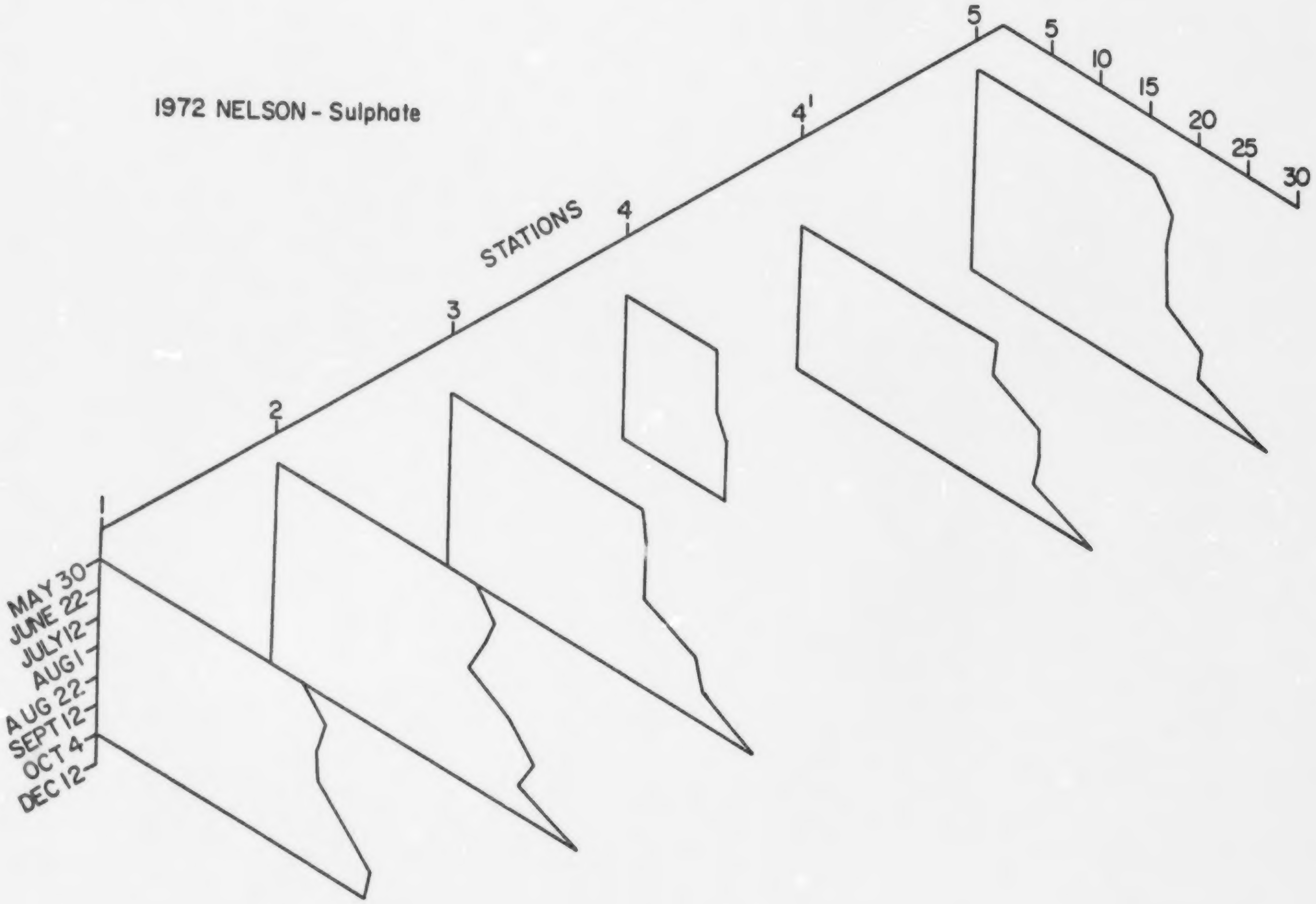
APPENDIX 5C

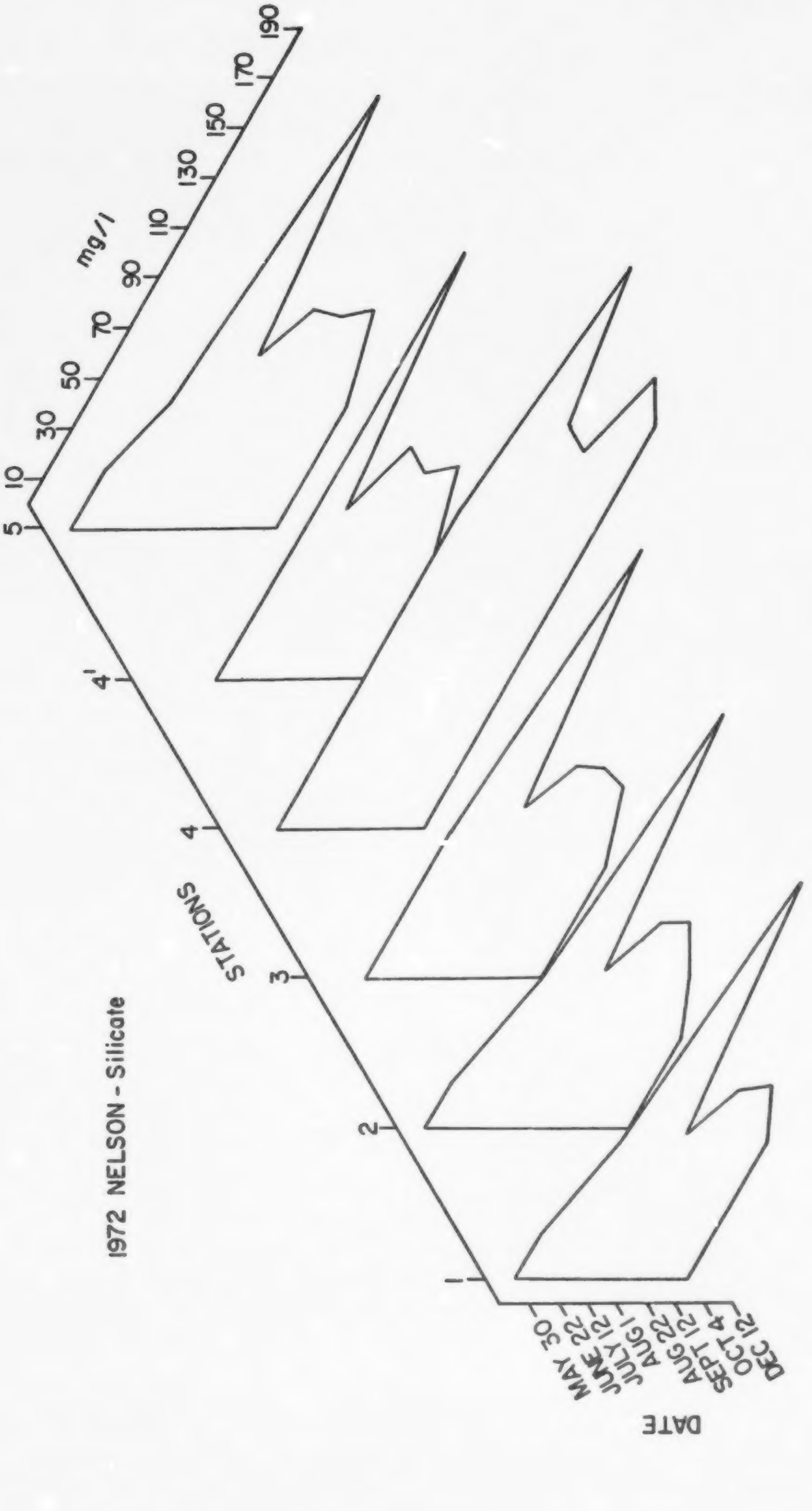
Temporal-spatial (time-station-concentration)
graphic illustration of measure chemical
species on the Nelson River, 1972



1972 NELSON - Chloride

1972 NELSON - Sulphate





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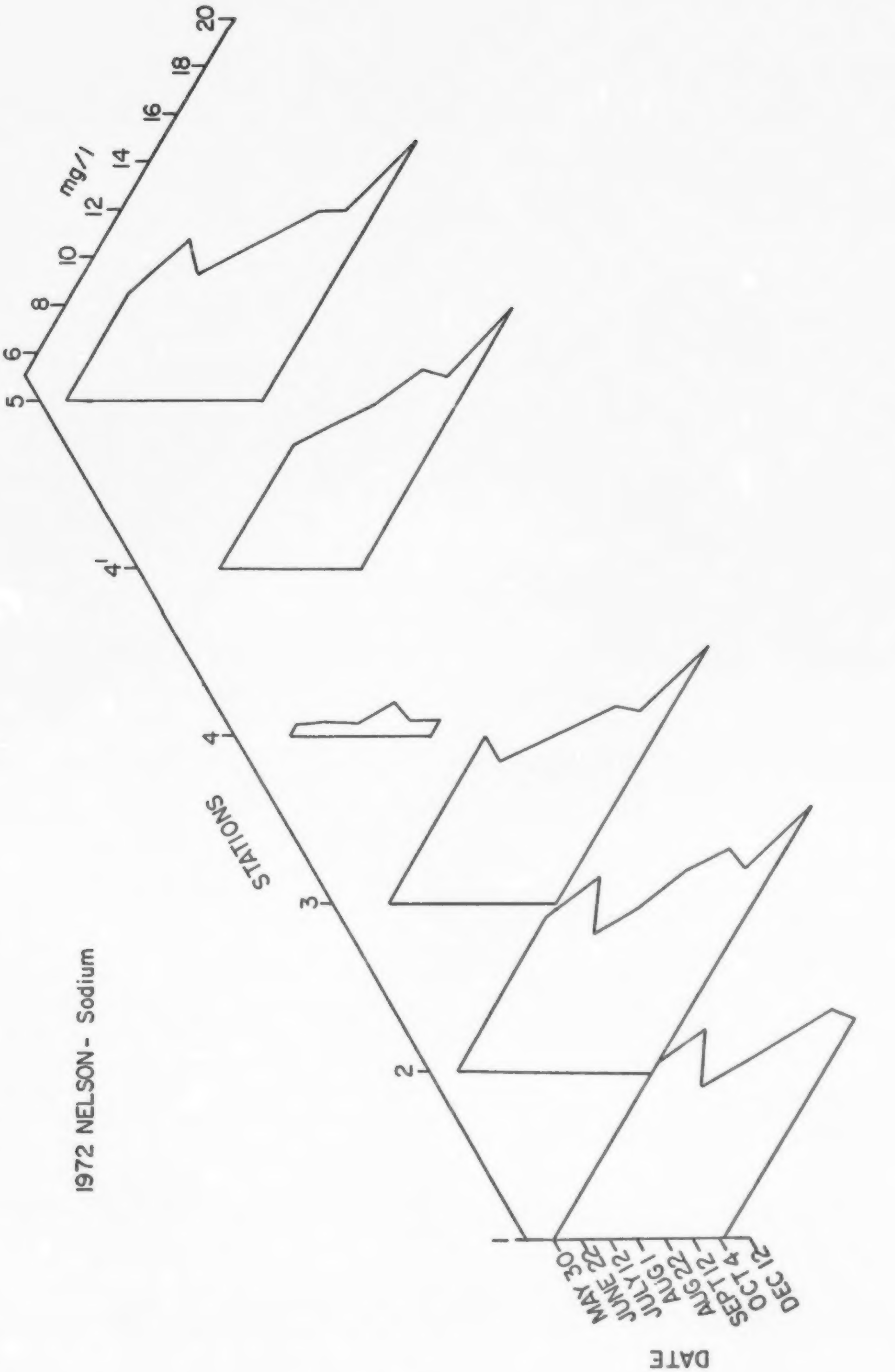
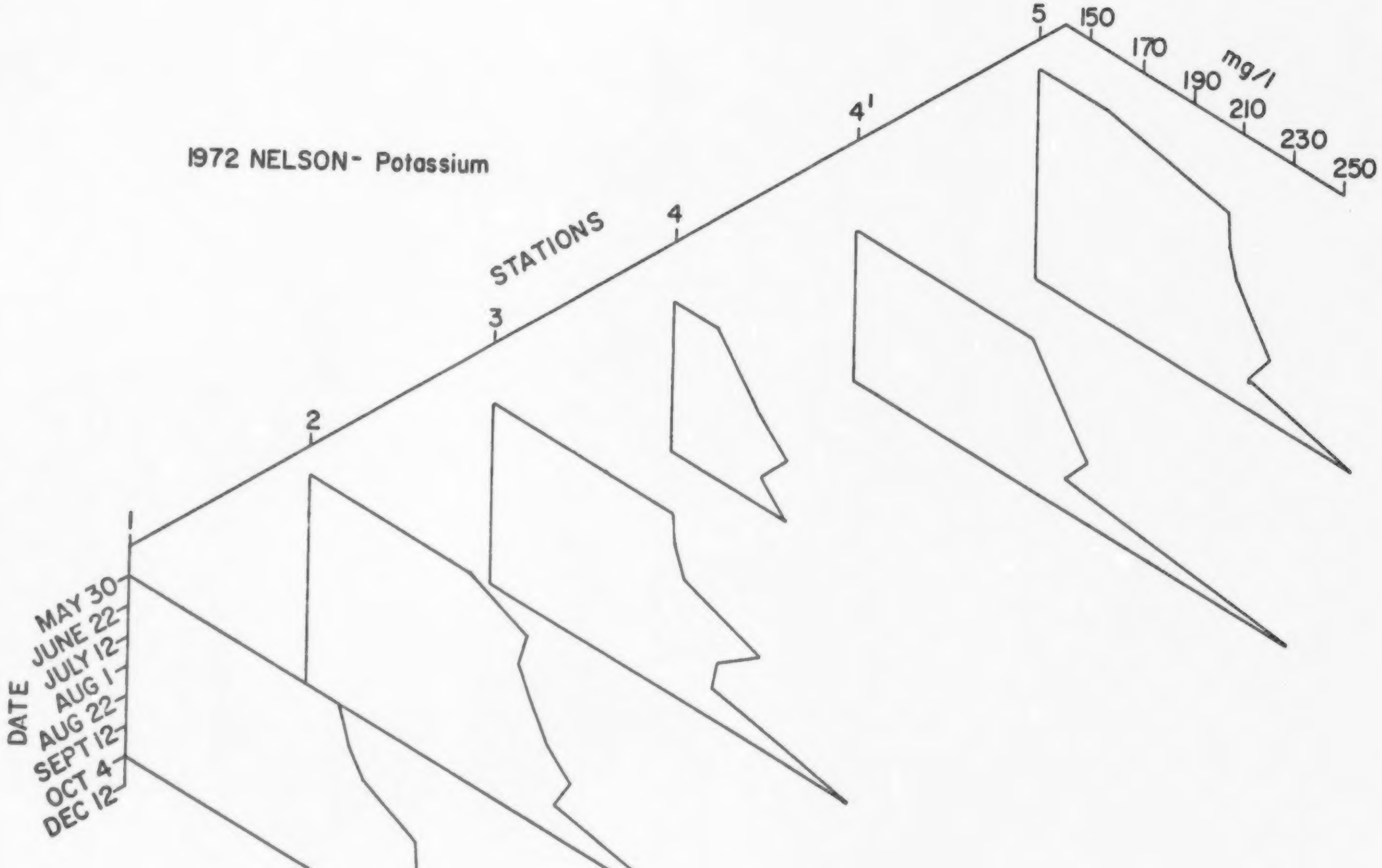
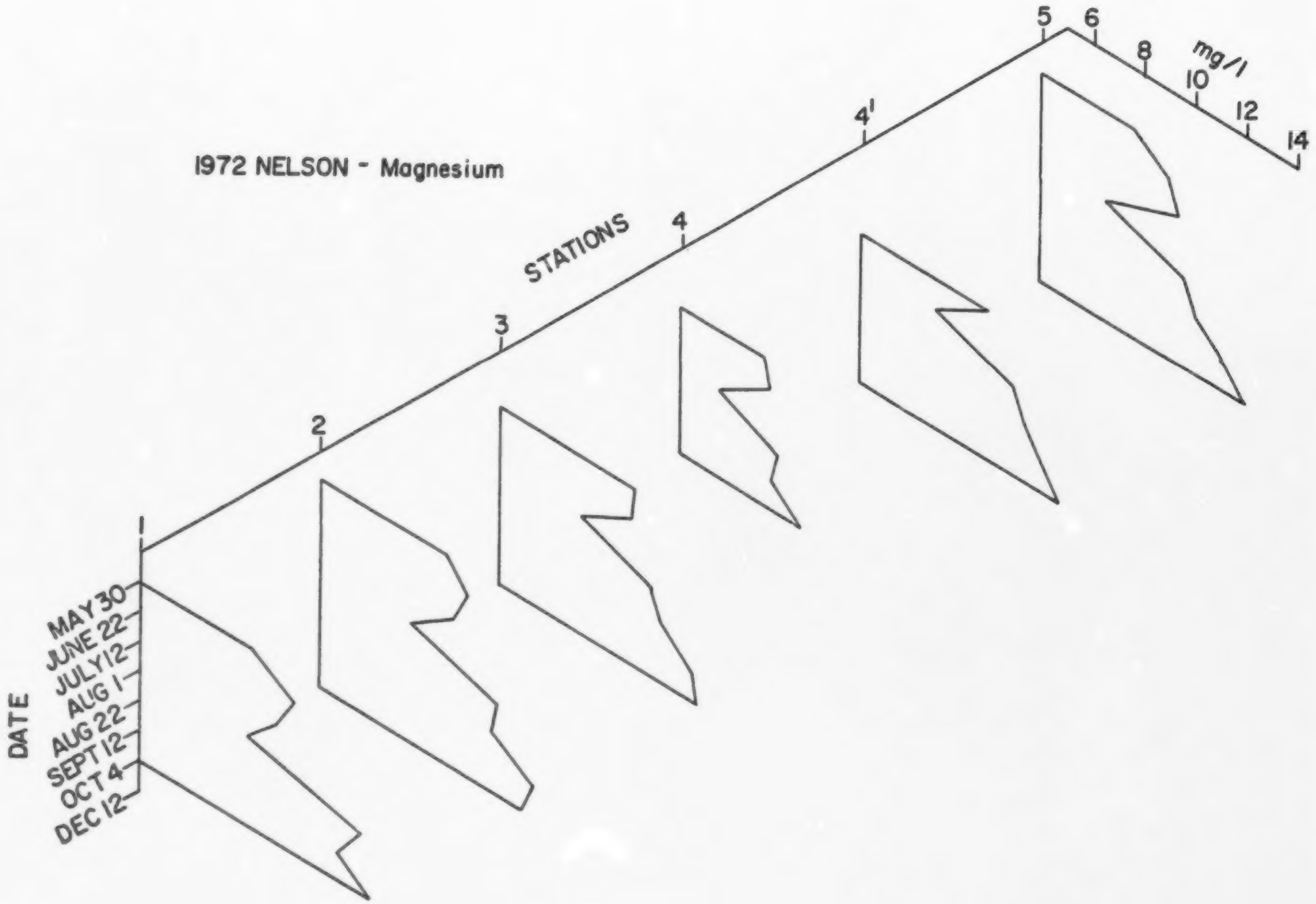


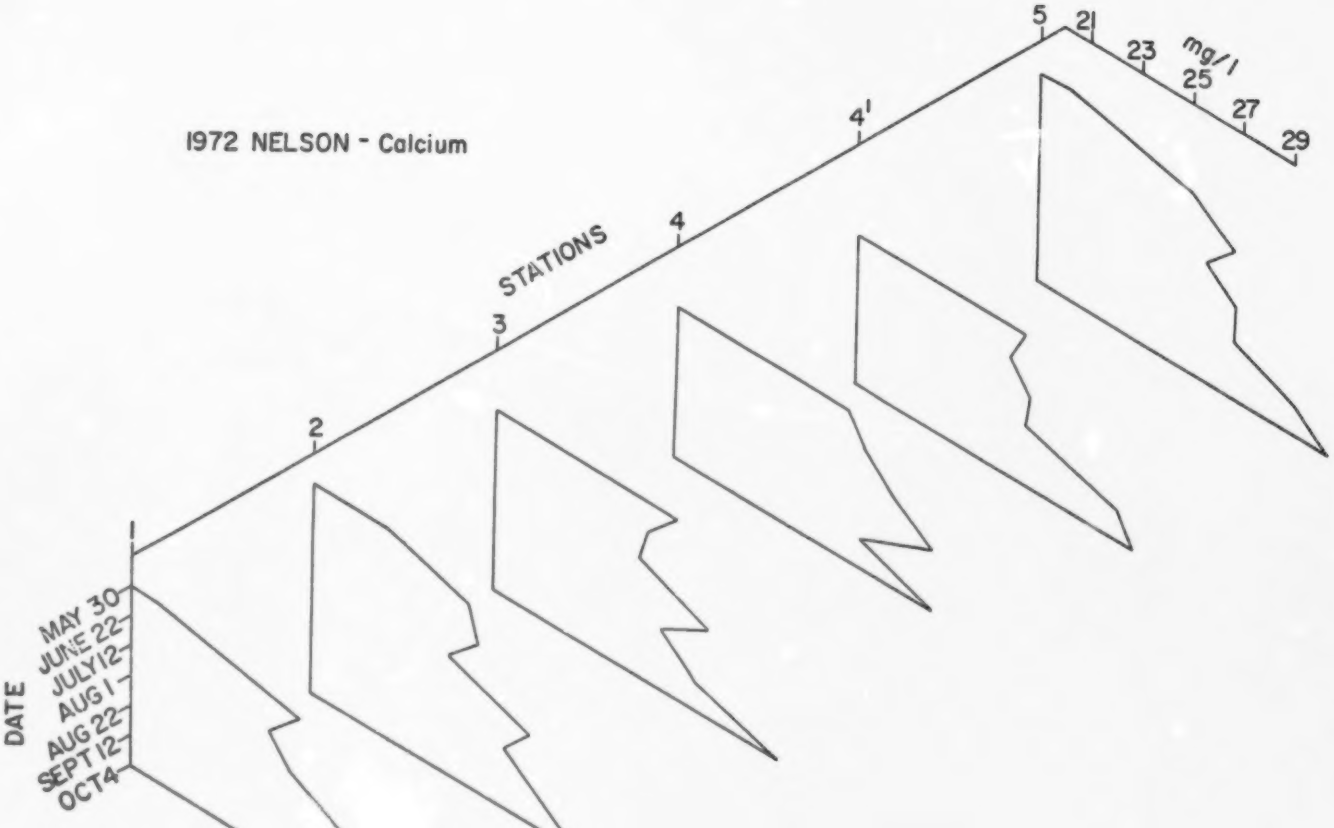
1972 NELSON - Sodium



1972 NELSON- Potassium

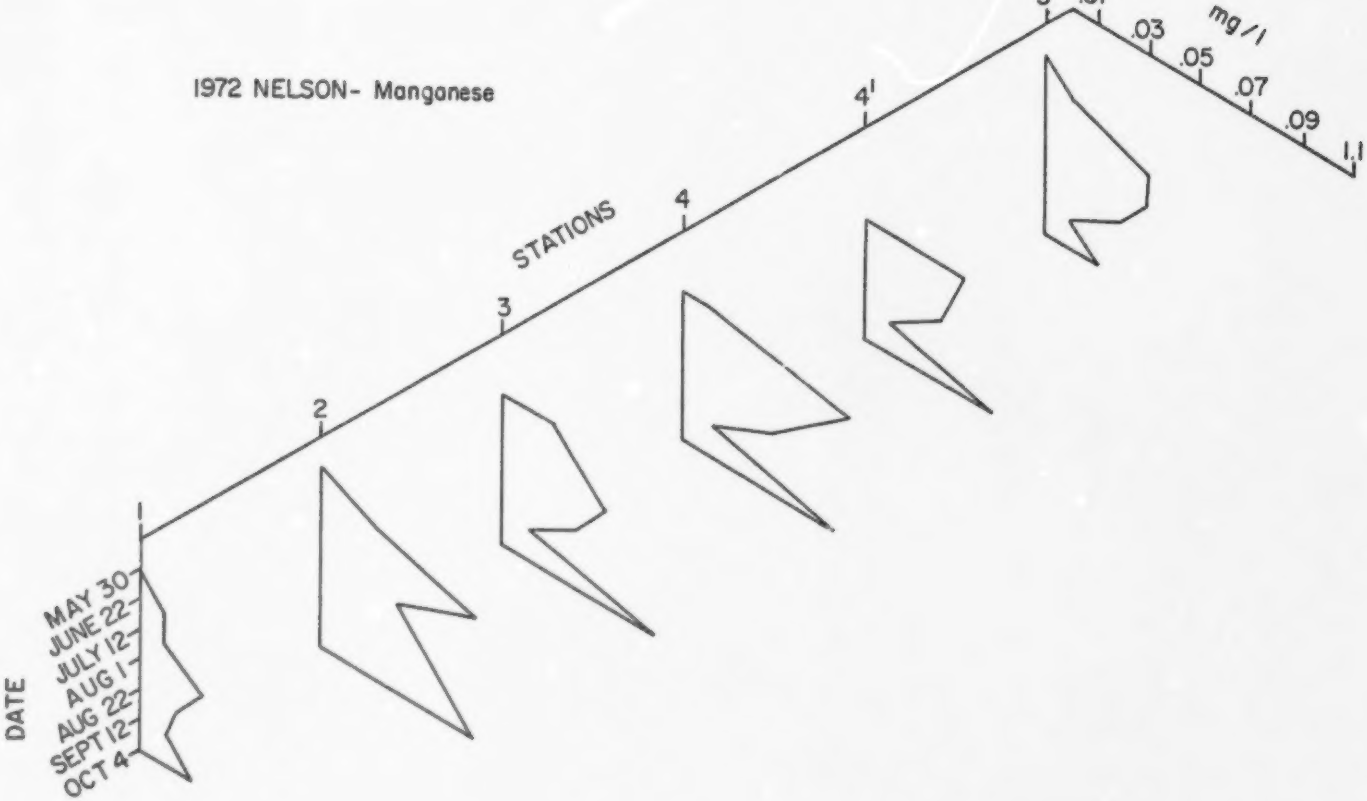
1972 NELSON - Magnesium

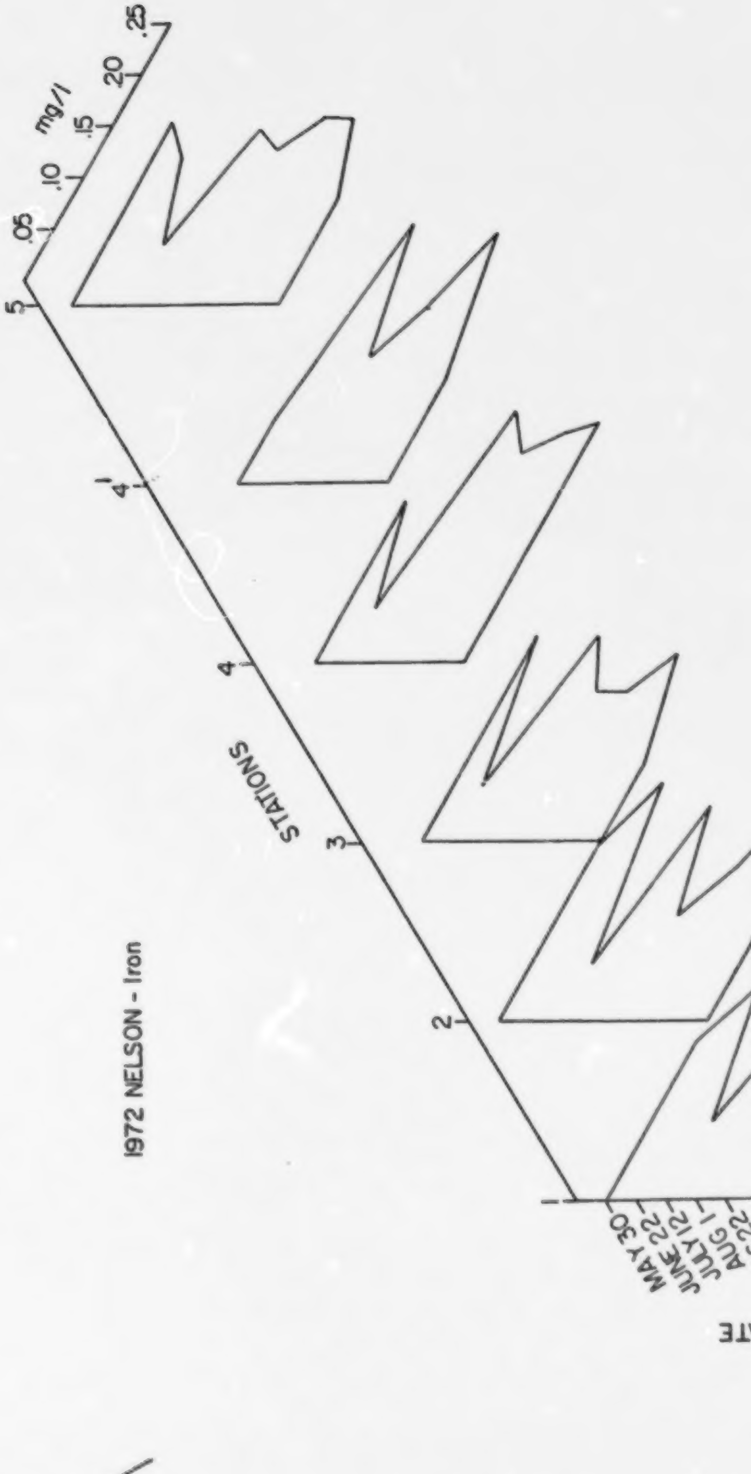




1972 NELSON - Calcium

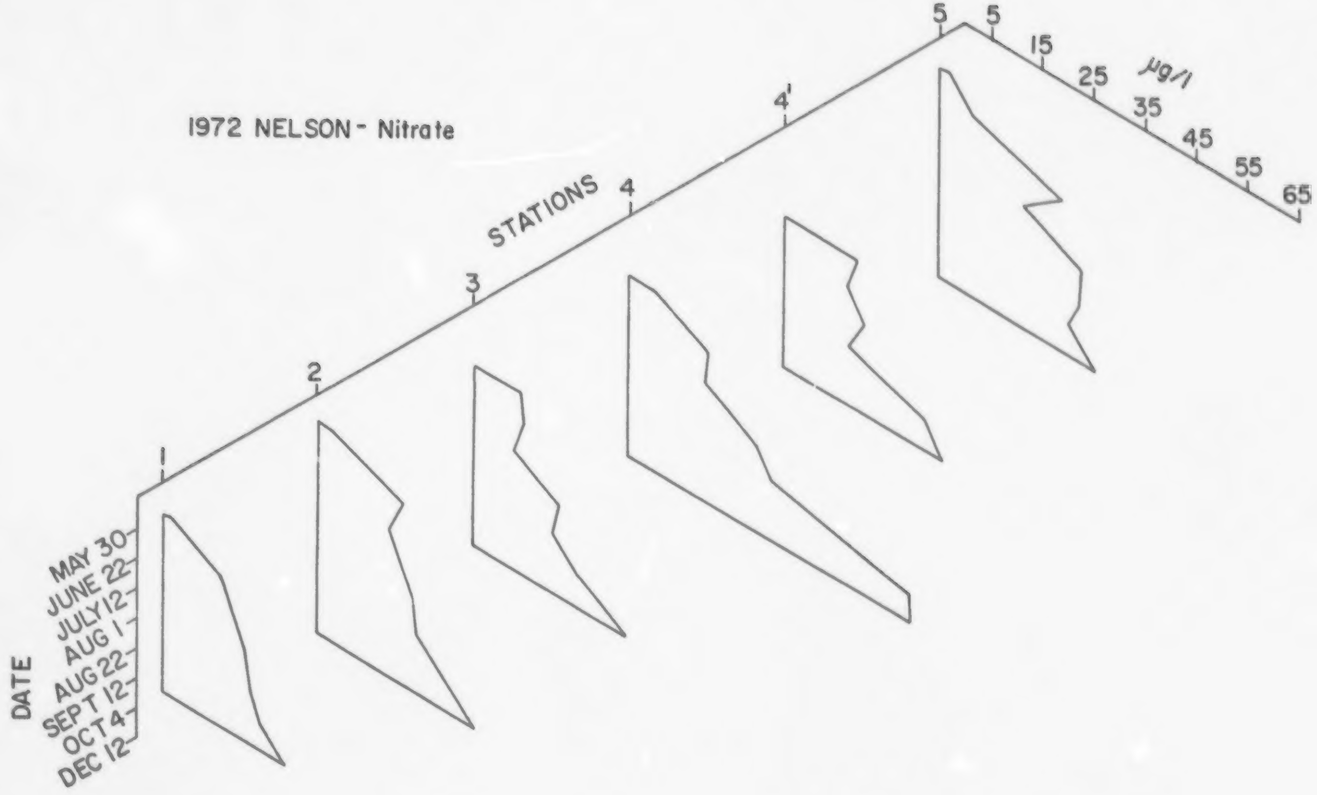
1972 NELSON- Manganese

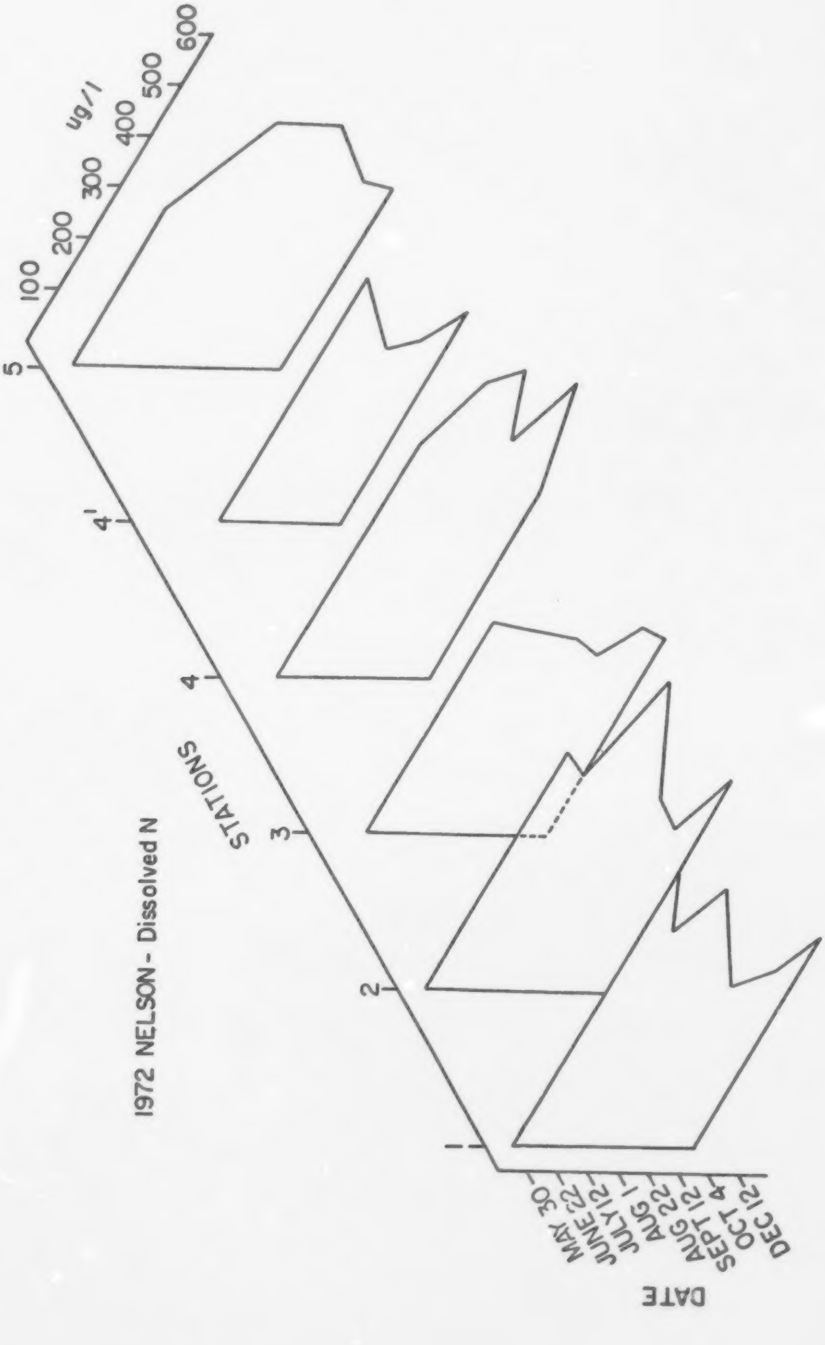




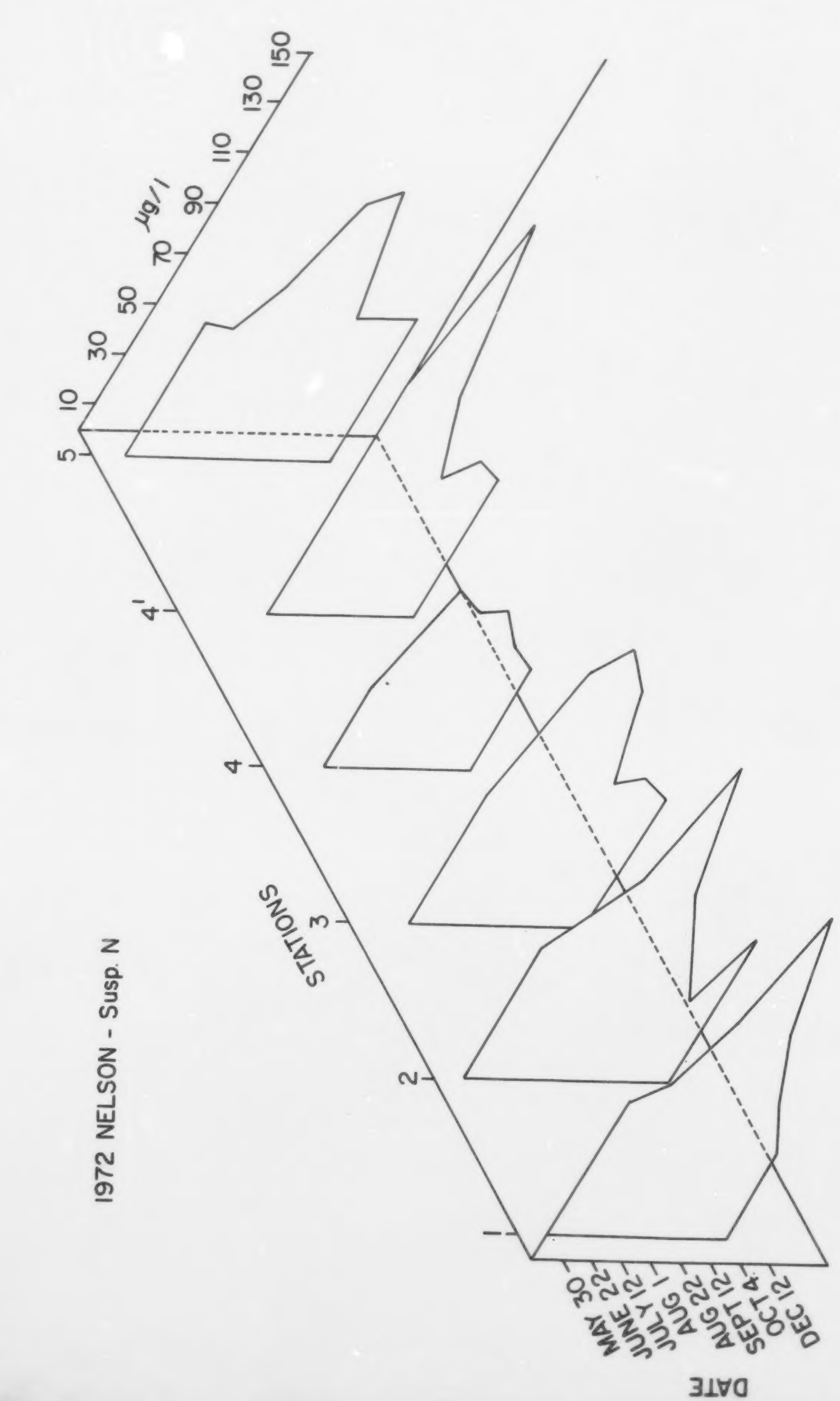
1972 NELSON - Iron

1972 NELSON - Nitrate

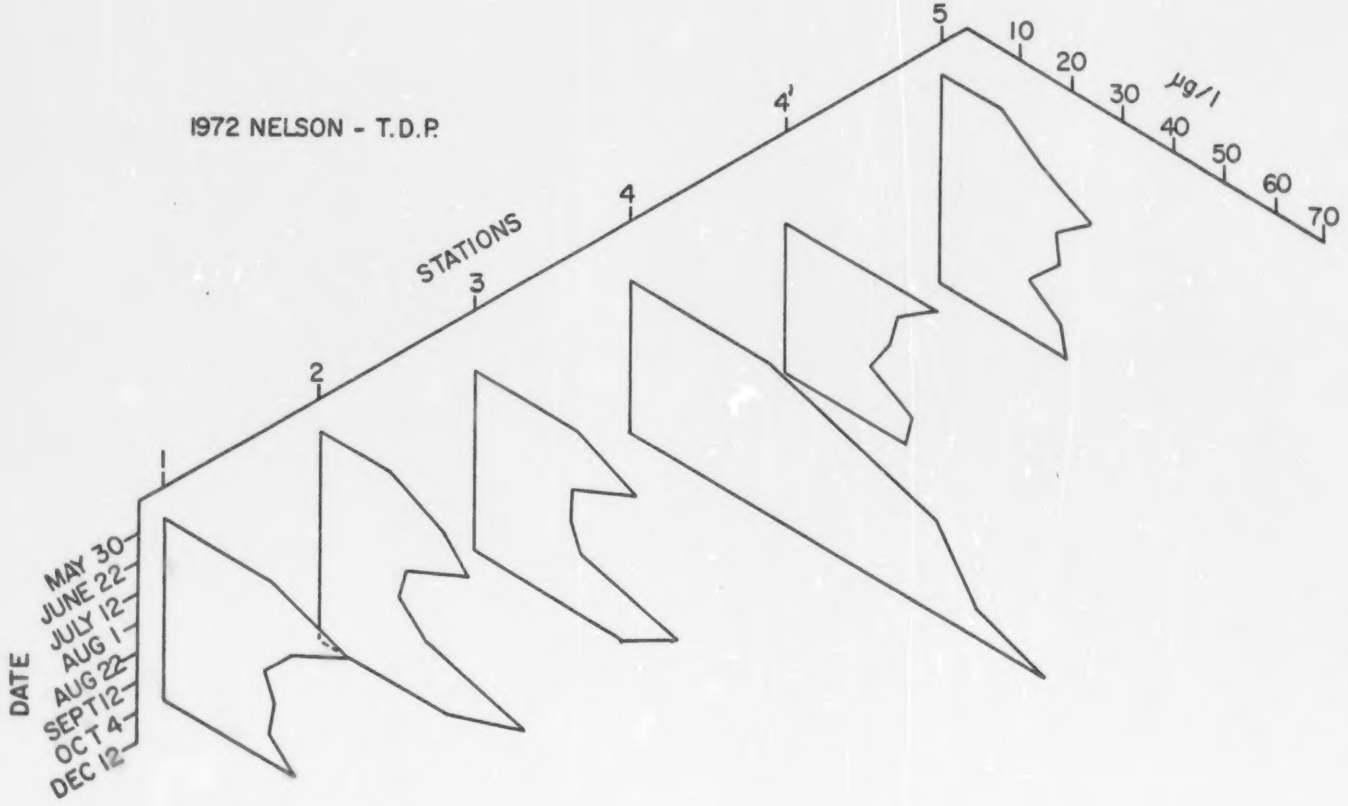




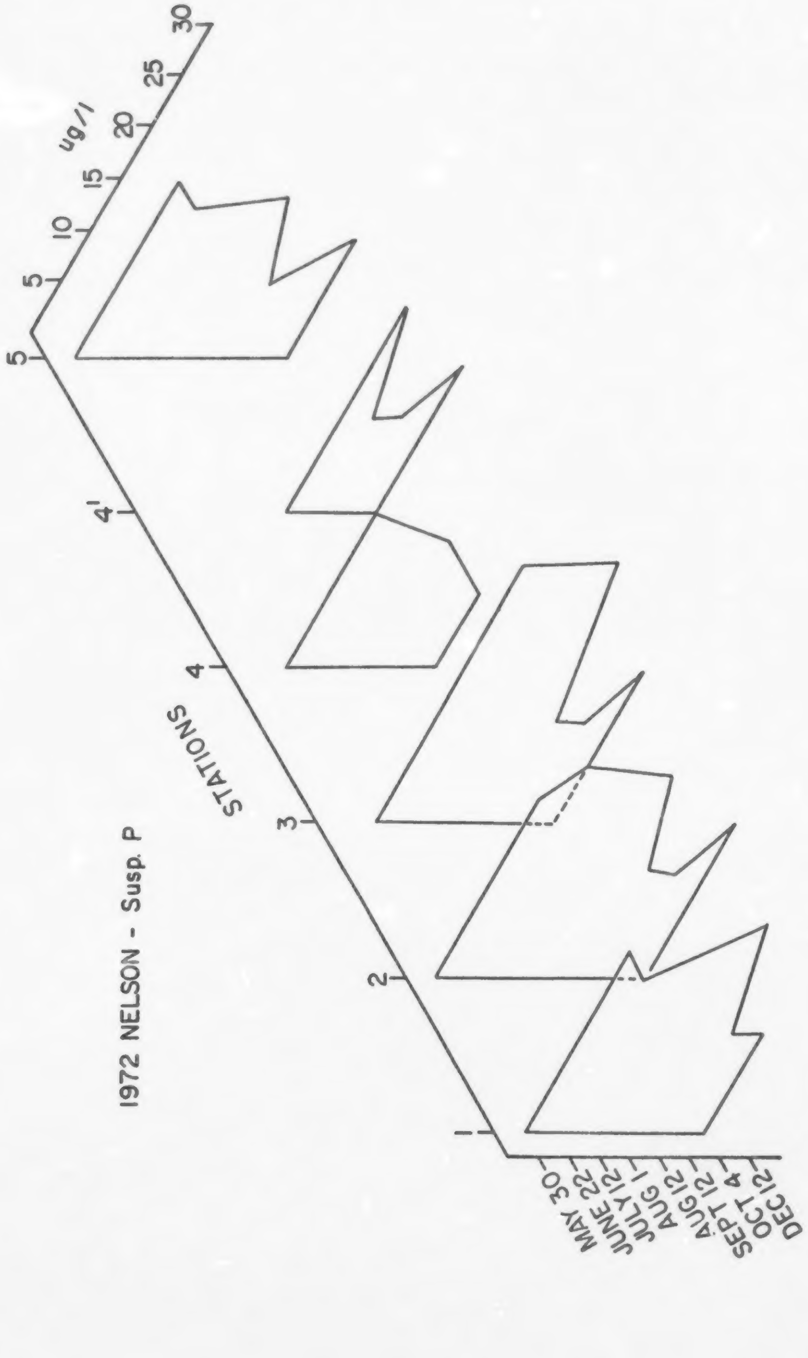
1972 NELSON - Dissolved N



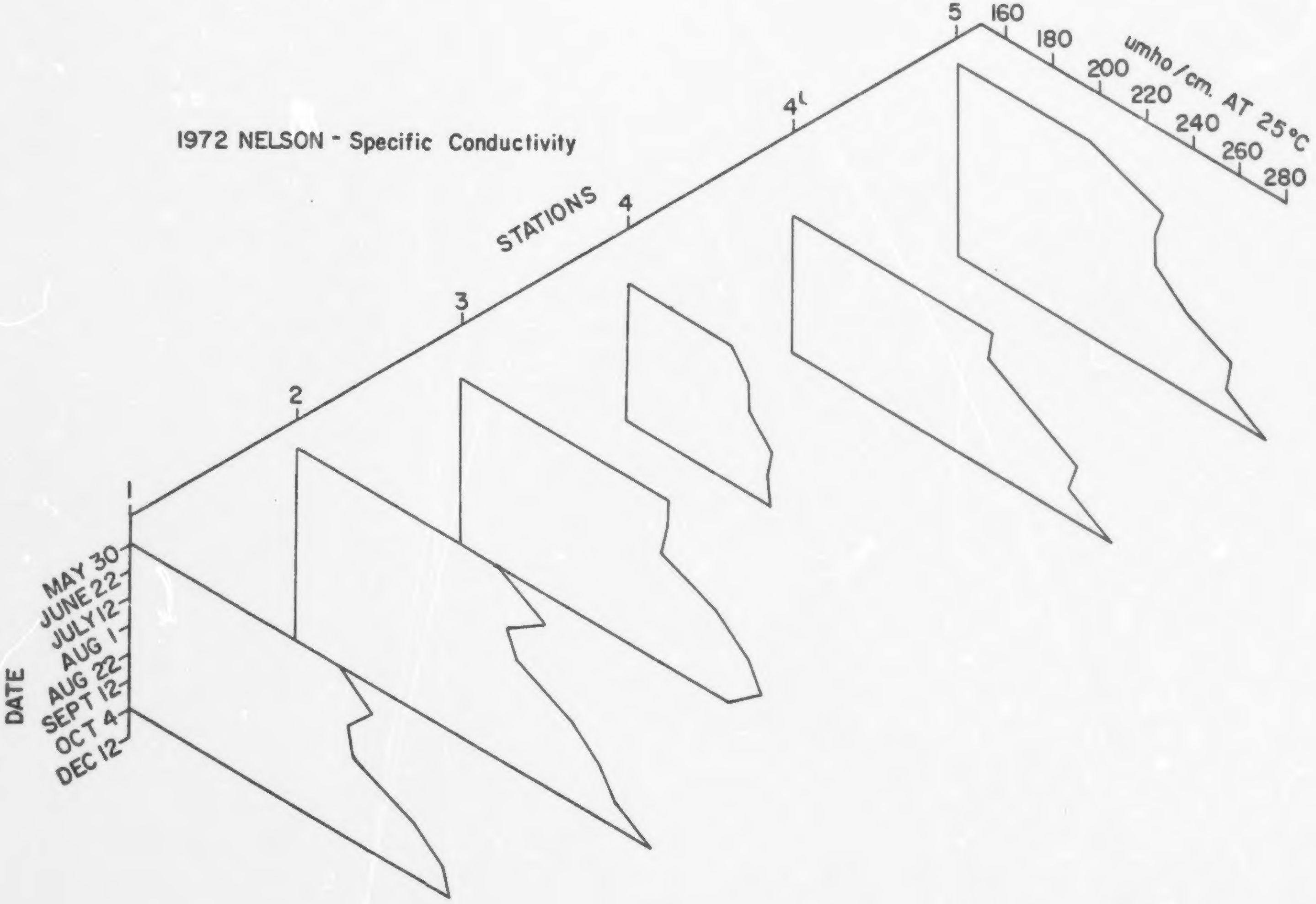
1972 NELSON - Susp. N

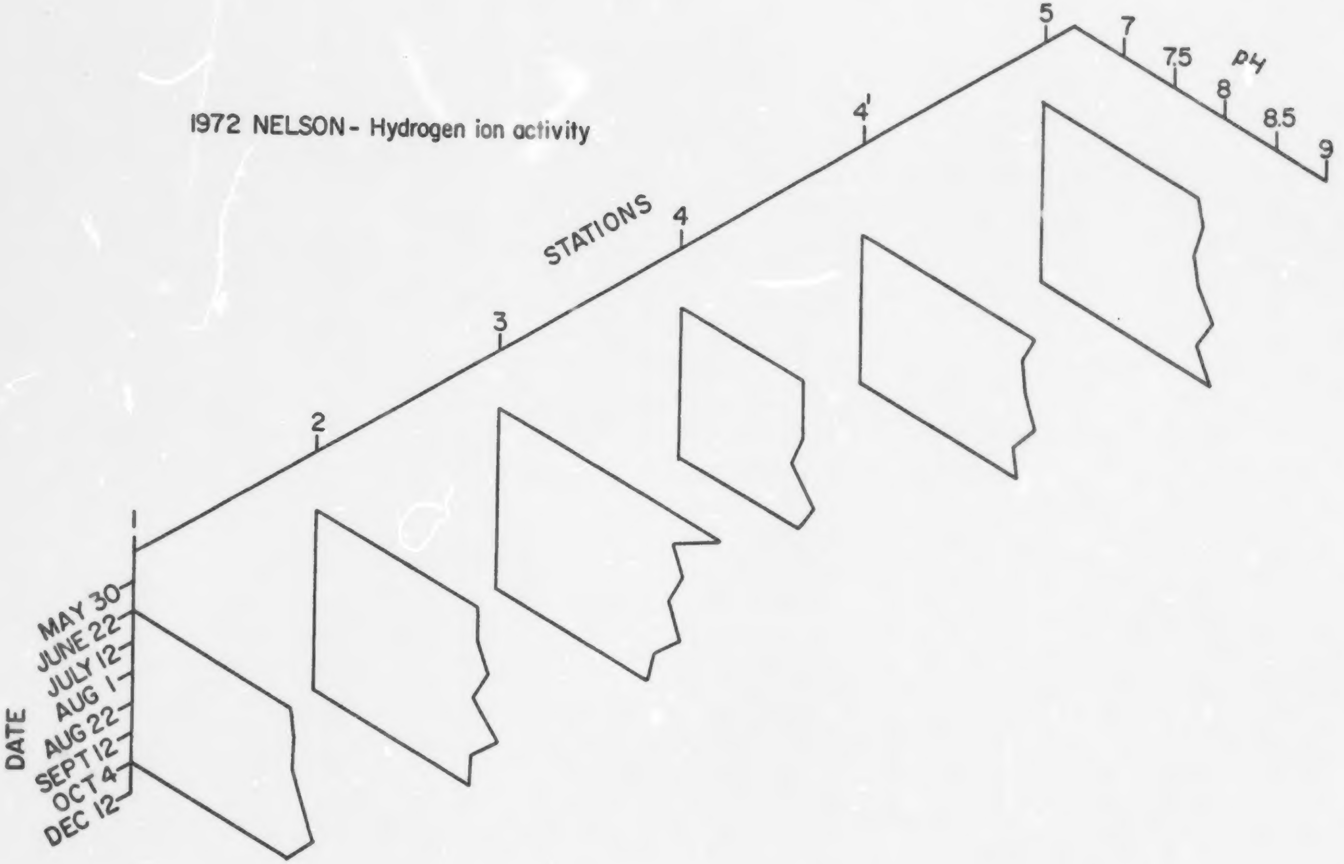


1972 NELSON - T.D.P.

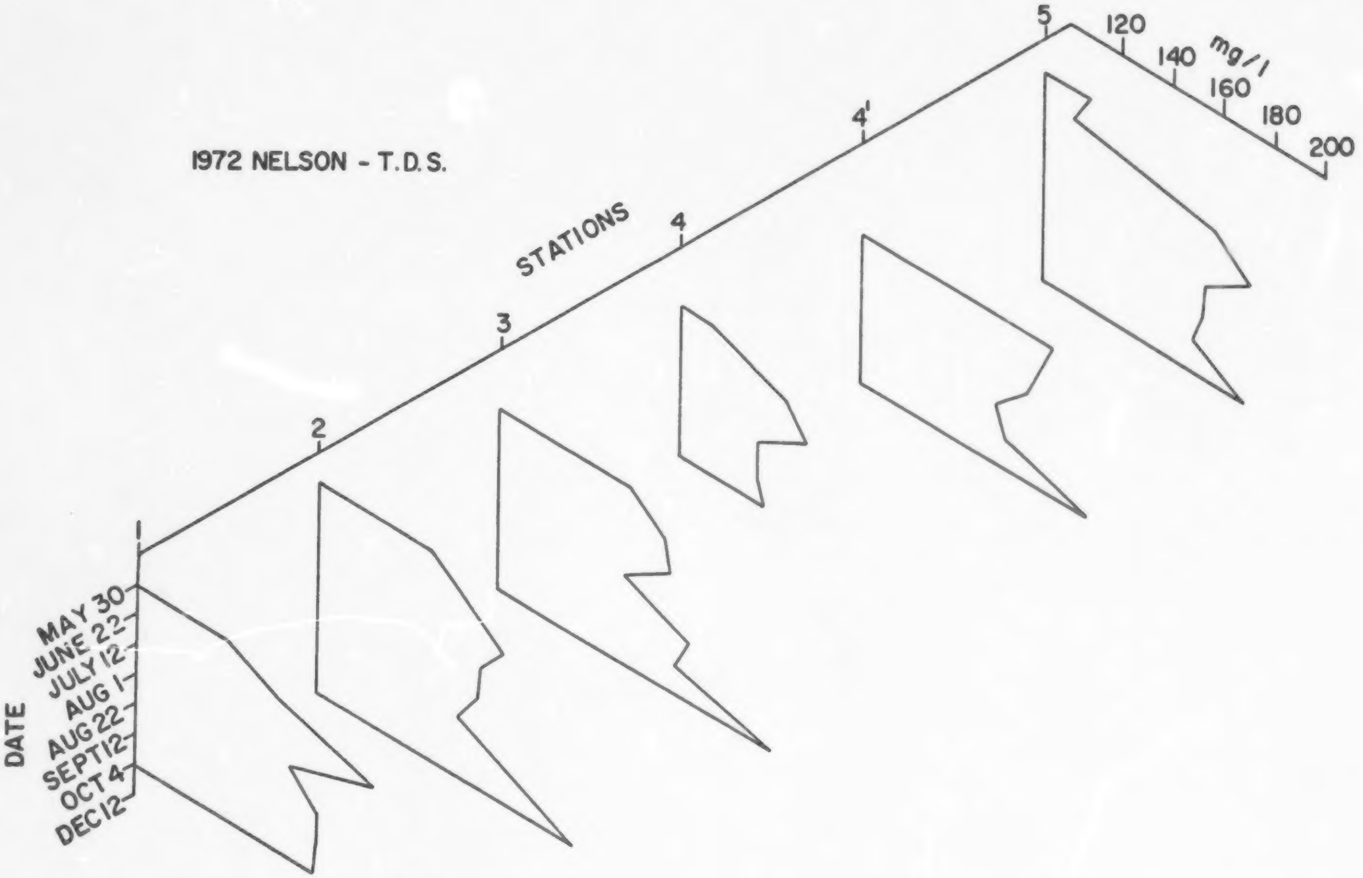

1972 NELSON - Susp. P

1972 NELSON - Specific Conductivity

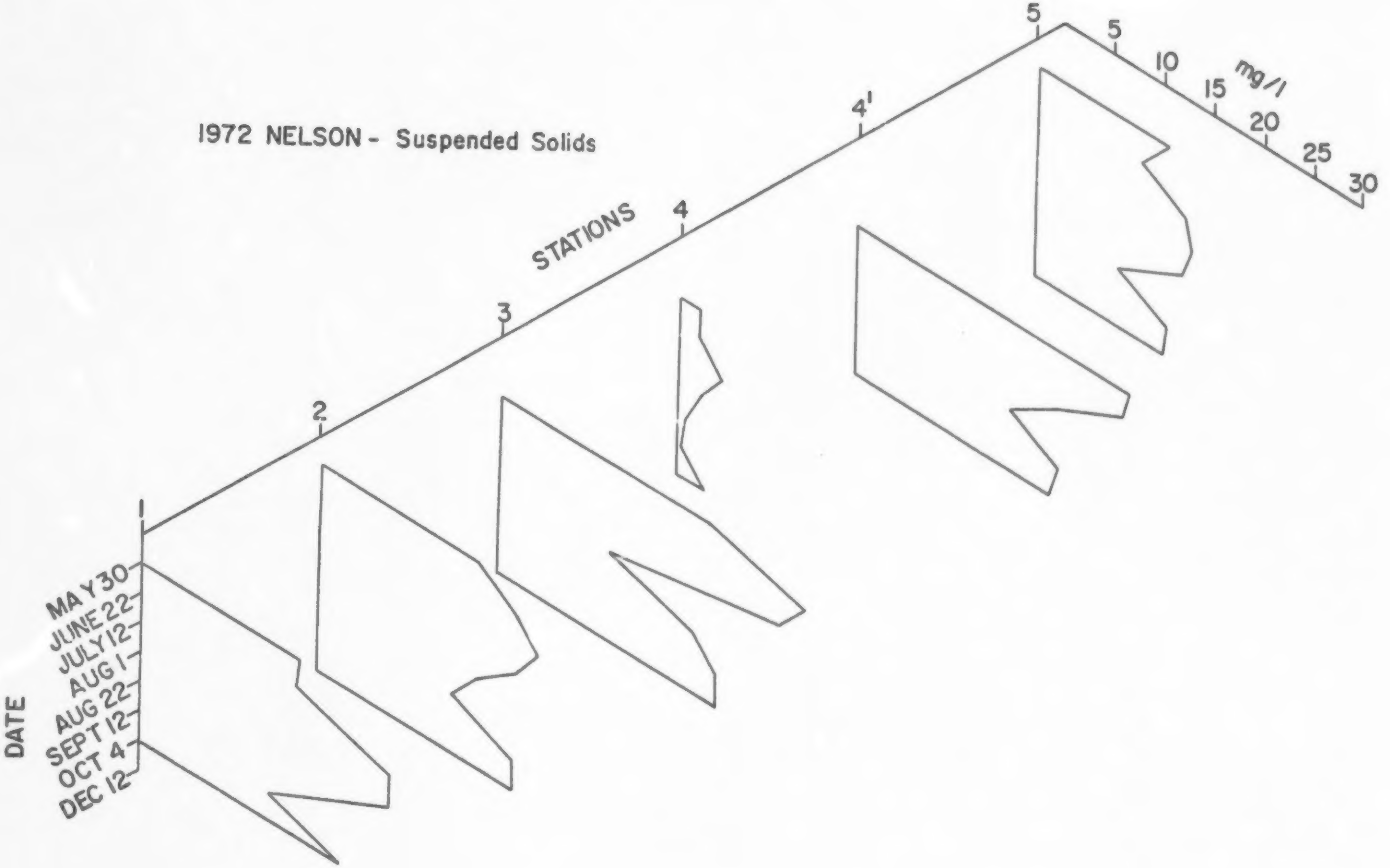



1972 NELSON - Hydrogen ion activity

1972 NELSON - T.D.S.



1972 NELSON - Suspended Solids



APPENDIX 5 - Vol. 2 -

Phytoplankton and Primary
of the Lower Churchill L
The Rat-Burntwood Lakes, and
River Lakes and Reservo

PHYTOPLANKTON AND PRIMARY PRODUCTIVITY OF THE LOWER CHURCHILL LAKES, THE RAT-BURNTWOOD LAKES, AND THE NELSON RIVER LAKES AND RESERVOIRS

by

R. E. HECKY and R. J. HARPER
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
August, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

ABSTRACT

The lower Churchill lakes in their mainstem portions im biomass from Southern Indian Lake. The magnitude and periodi standing crops is determined by events in Southern Indian Lak Missi Rapids. On the average standing crops decline during p through the lakes and the algae appear to be less active. Da integral rates of primary production are somewhat lower than Missi Rapids because of the lower activity and higher turbidi water areas have standing crops and integral productivity val 50% of the mainstem regions. Diversion without mitigation wi production to two-thirds its present value on a per unit area bring a decline of greater than 50% for total primary product lakes. Construction of rock weirs at the outlets and guarant minimum discharges would permit the lakes to maintain nearly levels of production.

The present Rat-Burntwood lakes are mesotrophic to eutr primary production. They have the highest average standing c study area and daily integral rates of primary production equ greater than Southern Indian Lake despite much higher turbidi Diversion and impoundment at Notigi will not drastically alte production over the present lake basins which will be on the River plume, but immediately after diversion when shoreline p most acute integral primary production will be lower than in Indian Lake because of turbidity problems. Backwater areas w

productive of algae than the mainstem but total aquatic primary production will be higher in the new reservoir because of the greater surface area. Lakes between Notigi and Thompson will have seriously degraded water quality because of channel erosion. Conditions in this reach will improve with the construction of Wuskwatim Reservoir.

Studies on the phytoplankton and primary production of the Nelson River Reservoir raise serious questions concerning the productivity of new reservoirs in northern latitudes. More research is required to explicate the role of soluble humic compounds in affecting primary production.

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ACKNOWLEDGMENTS

We wish to acknowledge the analytical laboratory of the Freshwater Insitute for performing many of the chemical analyses and particularly M. Capel and M.P. Stainton for valuable advice and assistance. D.W. Schindler and E.J. Fee also contributed time and consultation on methodology, and we are particularly grateful for making available the facilities of the Experimental Lakes Area as required. H. Kling confirmed many phytoplankton identifications as well as counting several samples. G.E. Porth prepared the final typescript. S. Zettler and the staff of the Graphic Arts Section of the Freshwater Institute prepared the figures.

1. INTRODUCTION

Chlorophyll-containing plants form the primary level of biological production in aquatic ecosystems. In most large lakes, phytoplankton constitute the overwhelming source of primary production while aquatic macrophytes and attached littoral algae are minor contributors. The energy fixing activities of primary producers place broad limits on the amount of production possible by herbivores, secondary consumers and ultimately fish stocks in lakes. Therefore, understanding of the quantity, quality, and spatio-temporal distribution of algal production in lakes is essential to explaining patterns of fish production and the likely consequences of fundamental changes such as those produced by hydroelectric developments proposed for the Churchill and Nelson Rivers.

The present study reports the results of surveys on the lower Churchill River lakes, the Rat-Burntwood lakes, and the Nelson River lakes and reservoirs. Information available include monthly (at least) phytoplankton samples taken in conjunction with chemical sampling (Cleugh 1974) at numerous stations in each river system during 1972 and 1973 and the results of primary productivity experiments conducted during September 1973. Within the time constraints imposed by the study, this information is considered adequate for preliminary description of algal production in the systems and to permit crude estimates of the likely affects of hydrological and hydrochemical changes associated with the development.

2. METHODS

The methods used in this study are identical to those employed on Southern Indian Lake (Hecky, Harper, and Kling 1974) for phytoplankton collection, preservation, and enumeration and for estimating primary productivity.

3. THE LOWER CHURCHILL LAKES

Below Missi Rapids on the Churchill River are three sizable lakes, Partridge Breast, Northern Indian, and Fidler, and one small lake, Billard which most properly can be considered part of the river. These lower Churchill lakes will undergo substantial hydrological and morphometric changes because of the Churchill Diversion and these changes are unique within the present development scheme. To evaluate the probable effect on the primary production of these lakes field investigations were conducted in 1973.

3.1. The seasonal cycle of phytoplankton:

In Figure 3.1 the changes in the quantity and taxonomic composition of algal biomass in the lower Churchill lakes are depicted through the June to September open-water season. Changes in algal populations in Wood Lake, a nearby lake receiving only local drainage, are also shown to demonstrate unique aspects of those lakes on the Churchill River. With the exception of the August sample from Partrid Breast Lake, the three lower Churchill lakes, Partridge Breast, Northe Indian, and Fidler have algal populations with similar magnitude, taxonomic composition and periodicity to Missi Falls, the outlet from Southern Indian Lake. As at Missi Falls the waxing and waning of diat populations, primarily of Melosira spp. determines the changes in tota algal biomass. Spring and autumn maxima separated by a mid-summer minimum were found at Fidler, Northern Indian, and Missi Rapids in

1973 and this is identical to the periodicity observed in the northern regions of Southern Indian Lake and inferred for the remainder of the lake in 1972 (Hecky, Harper, and Kling, 1974).

Partridge Breast Lake appears to differ from this paradigm because of its relatively high biomass in August. However, much of this biomass is constituted of surface-blooming blue-green algae (Cyanophyta) which may be locally over-represented. It is quite clear from Figure 3.1 that stations on the Churchill River plume differ substantially from Wood Lake. Diatoms were never quantitatively important in the Wood Lake samples, and the periodicity of Wood Lake, as well as can be determined, tends toward a summer maximum.

The maximum biomasses attained at Missi Rapids in the lower Churchill lakes and Wood Lake would just qualify them as mesotrophic by Vollenweider's classification. Average biomasses for the open-water season show an appreciable decline from Missi Rapids through Fidler Lake suggesting that losses to respiration, grazers (zooplankton) and sedimentation exceed production on the average through this stretch of the river. Partial explanation, at least, can be found in declining transparency below Missi Rapids (Cleugh 1974 and Table 3.1) shrinking the depth of the euphotic zone and imposing a declining net production. The declining transparency is likely the result of suspended silts acquired by the stronger river currents below Missi Rapids.

The similarity among algal crops at Missi Rapids and the lower Churchill lakes in magnitudes, species composition and periodicity combined with the general decline of algal biomass through the lower lakes implies that Southern Indian Lake through its outlet at Missi

Rapids exports much of the biomass found in the lower lakes. Morphometric and chemical data also suggest that the Churchill plume moves from Missi Rapids through Fidler Lake in less than one week. This short turnover time supports the likelihood that much of the biomass in the lower lakes is imported.

3.2. Primary production:

On 25 September 1973 water samples were taken in order to estimate the photosynthetic activity of the phytoplankton. Although the rates determined cannot be extrapolated for the whole year they allow comparison with productivity values from Southern Indian Lake (Hecky _et al_., 1974) and the Rat-Burntwood lakes for which similar experiments were run at the same time. The sampling locations (Figu 3.2) were chosen to investigate the relative magnitude of production on the Churchill River plume and production in areas not directly influenced by the river. It is important to realize that off-plume locations were remote from the plume but in no sense were they isola by land barriers. The results of the production experiments are giv in Table 3.1. The daily integral of primary production (total photosynthetic carbon fixation below one square meter during a full day) calculated using a theoretical day of full sunlight in the manner des cribed by Hecky _et al_. (1974). The value does not represent _in situ_ production for 25 September, but it is comparable with all other production values obtained in this study.

There is a clear and undeniable differentiation between the o plume lake stations and off-plume stations including Wood Lake. On-p stations have nearly twice the standing crop of their paired off-plum station. The productivity at optimum light (P_{opt}) is 50-100% higher. However, the on-plume stations also have higher light extinction coefficients, but the daily integral of production for on-plume station is still 50-100% higher by diatoms while off-plume stations were domi other algal groups. The positive influence of the river importing algal biomass and water suitable for continued algal activity from Southern Indian Lake could not be clearer.

While the on-plume stations are significantly more productive than off-plume stations in the lower Churchill, these on-plume statio are less productive than stations above Missi Rapids visited contemporaneously. The values of P_{opt}, 10-11 mg $C.m^{-3}.hr^{-1}$, are roughly two thirds the measured values at stations 40 and 47 in Southern Indian La 16-18 mg $C.m^{-3}.hr^{-1}$ (Hecky et al., 1974). However, the lower Churchi stations were of necessity sampled in late afternoon, and there is evidence that algal activity declines near sunset (E.J. Fee, personal communication) to roughly 50% of its midmorning value. Therefore, th observed differences in P_{opt} may be artifacts of sampling. The Southe Indian Lake stations are more transparent (extinction coefficients, 0.85 to 1.0 in units m^{-1}) so it is quite likely that the daily integra production in Southern Indian Lake above Missi Rapids is significantly higher (estimated integral rate of 910 to 890 mg C $m^{-2}da^{-1}$ versus the maximum observed in the lower Churchill lakes of 490 mg C $m^{-2}da^{-1}$).

Much of the algal biomass in the lower Churchill lakes is imported from Southern Indian Lake. The activity of the algae at optim light is probably similar to that in Southern Indian Lake, but environ-ted by

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mental light conditions decline through the lower lakes so that
daily integral and net column production declines from Partridg
through Fidler Lakes. The end result of this is that on the av
lower biomasses are observed at Fidler Lake than at Partridge B
The turnover time of the water in these lakes is quite short (1
a week for on-plume stations) so there is little chance to modi
significantly the algal populations imported from Southern Indi
In lake areas off the mainstem quite different algal population
photosynthetic activity are observed. These are much lower tha
observed values on the plume and indicate that waters not excha
rapidly with the Churchill River are much less productive. Thi
clusion is similar to that reached by Hecky _et al_. (1974) for S
Indian Lake.

3.3. Impact of diversion:

When Manitoba Hydro diverts the Churchill River out of S
Indian Lake there will be substantial changes in the water elev
surface areas, and volumes of the lower Churchill lakes (Brown
e.g. mean surface areas will decline by 24 to 70% under long-te
flows. The control sections for these lakes tend to be deep wh
allows surface area and volume to decline with discharge, and f
reason the turnover time of the lakes will not change drasticall
(increase will probably be two to three days). It can be expect
that primary production in the lakes will still be in large part
on imported biomass from Southern Indian Lake. Previous impact
ment on Southern Indian Lake (Hecky _et al_., 1974) has suggest th

production in the northern region of Southern Indian Lake will de
to approximately two-thirds its present level. Changes of simila
magnitude can be expected in the lower Churchill lakes.

The general pattern of biomass decline through the lower l
will likely be aggravated by degraded transparency after diversio
The lower mean water levels will expose lake sediments deposited
the depth of wave action under the old regime to the erosive powe
breaking waves. The much greater relative fluctuation in dischar
elevation after diversion will increase the effectiveness of this
erosion. Annual maximum discharges after diversion will be nearl
greater than the annual minimum as opposed to 50% greater under t
present regime, and this variability in discharge translates to i
variability in water levels. As this variability will occur annua
there will likely be broad areas of unstable shoreline and littora
areas bordering the new lake. These areas will supply the silts a
clays which will render the lower lakes more turbid than at presen
In summary primary production will likely fall to at least two-thi
its present level, and depending on the severity of shoreline prob
it could decline much farther.

The Fisheries-Limnology sector will recommend the construct
of weirs on the lower lakes and the establishment of higher minimu
discharges at Missi Rapids primarily to preserve aquatic habitat a
prevent potential violation of the Federal Fisheries Act. These
mitigation measures would largely offset much of the expected impa
on primary production. A guaranteed annual discharge of 5,000 cfs
Missi Rapids would ensure that there are no catastrophic changes i

productivity of Southern Indian Lake and that a reasonable s
algal populations and nutrients would be imported into the l
Churchill lakes. Maintaining lake levels at or near their p
and giving them a control section less dependent on dischar
remove the erosion problems. The lower discharge, 15% of th
level, combined with the same volume maintained by weirs wou
increase the turnover time. A longer residence time would a
clarification by sedimentation and it would also allow more
utilization of the nutrient loading which in theory would b
to maintain a mesotrophic to eutrophic lake (Cleugh 1974).
production would likely remain near its present level under
gation procedures.

4. THE RAT-BURNTWOOD LAKES

The Rat-Burntwood river system will be the new course for the Churchill River after diversion. From Issett Lake its headwater, to Threepoint Lake where the Burntwood River joins it, the Rat River widens into five other mainstem lakes, Karsakuwigamak, Pemichigamau, Rat, Notigi, and Wapisu from north to south. In addition within the Rat drainage there are several other lakes, three Mynarski lakes and Suwanee Lake which are headwater lakes. All these lakes with the exception of Suwanee and Wapisu will be amalgamated into one large reservoir behind the dam at Notigi. Below Threepoint Lake on the Burntwood River there is one large lake, Wuskwatim, before a long riverine reach leading to Split Lake on the Nelson River. The most immediate proposal for Hydro development on the Burntwood after Notigi will be a reservoir at Wuskwatim Lake.

4.1. The seasonal cycle of the phytoplankton:

There are some quite distinct differences between the algal populations of the Rat-Burntwood and the lakes on the Churchill River. The quantity of algal biomass, its taxonomic composition and its periodicity in lakes on the Rat-Burntwood system is shown in Figure 4.1. Whereas diatoms dominated the algal maxima in Southern Indian Lake and the lower Churchill, cyanophytes, especially Anabaena and Aphanizomenon spp., tend to predominate at maxima with diatoms playing a subordinate role. By analogy with other lakes this species shift can be indicative of the Rat-Burntwood

Lakes being more eutrophic. The maximum biomasses attained, 3,500-6,600 mg.m^{-3} would classify these lakes as mesotrophic by Vollenweider's (1968) criteria (with the exception of Karsakuwigamak). These maximum standing crops are of the same magnitude achieved during algal maxima in the northern region of Southern Indian Lake and are somewhat higher than maxima in other regions of Southern Indian Lake. These standing crops are achieved in waters which are much less transparent than Southern Indian Lake (Cleugh 1974a and b) which probably implies that nutrients are more readily available in the Rat-Burntwood system (cf Hecky _et_ _al_., 1974).

The mean summer biomasses increase regularly downstream from Karsakuwigamak to Wapisu before declining at Wuskwatim after the Rat merges with the Burntwood. A similar phenomena was noted in Southern Indian Lake along the axis of flow, but unlike Southern Indian Lake this cannot be correlated with any clarification of the water (Cleugh 1974b and see the extinction values in Table 4.1). Rather the downstream increases are probably attributable to each lake receiving algae from upstream, increasing the biomass in the lake and passing the resulting higher biomass onto the next lake. The turnover times for each lake generally exceed one month (Brown 1974) which is adequate time for in-lake processes to modify imported algal biomass.

The periodicity of algal populations in the Rat-Burntwood is quite different from the Churchill lakes. There is no evidence for spring and/or fall maxima except perhaps in the Mynarski Lakes. It is possible that our initial sampling was too late to observe a spring pulse as was the case in certain areas of Southern Indian Lake in 1972, but if one occurred we would expect some trace in the downstream lakes. Although several phytoplankton samples for June 14 were lost, the chlorophyll values indicate small populations in all the lakes at that time. A rather regular rise and fall through the summer is the case with most lakes, except Wapisu, exhibiting an August maximum. This simple rise and fall pattern follows the annual temperature cycle fairly well as is a typical pattern for river (Williams 1972) where light and temperature more significantly affect algal growth than nutrients. Only in the most downstream lake on the Rat River, Wapisu, where the highest biomass occurs are nutrients likely to be a problem.

The Mynarski Lakes which have a total turnover time exceeding one year had the highest algal biomasses in the Rat-Burntwood system even though they are headwater lakes. High river discharge which was shown to be important on the Churchill system to maintain adequate nutrients is not so important in the Rat system. In the Churchill system mainstem stations were consistently more productive than back water areas or headwater lakes, but in the Rat basin there are no clear differences. This suggests that weathering of surface materials in the Rat basin supplies sufficient nutrients to maintain good algal growth in these relatively small lakes. There are extensive and thick clay deposits within the Rat-Burntwood basin, and these deposits are likely the source of the nutrients. In contrast much of the Churchill basin in Manitoba and Saskatchewan is typical Shield physiography with only scattered and thin surficial deposits. As well as supplying nutrients these clays also supply abundant suspended materials which account for the high turbidities in the Rat and Burntwood Rivers. This high turbidity and consequent low light penetration accounts for the very small phytoplankton populations in the Burntwood River station below Thompson (Figure 3.1).

4.2. Primary production:

Two sampling trips for primary production measurements were made to the Rat River lakes in 1973. On 30-31 August nine stations were made on Pemichigamau, Rat, Notigi, Wapisu and Mynarski. The first four lakes had paired samples taken while only one sample was taken from Mynarski. On Pemichigamau, Notigi, and Wapisu Lakes paired stations were made, one on and one off what was considered to be the river plume; on Rat Lake stations were made at the inlet and outlet to estimate the affect of residence in the lake on the growth of algal populations. On 24 September each of the lakes was again sampled, but only at mainstem stations. The results are given in Table 4.1 and in Figure 4.2 along with the locations.

The differences between on-plume and off-plume stations are obscure and there is no clear relationship as there was on the Churchill system. In Pemichigamau the mainstem station had a higher biomass, but the activity at optimum light was lower than the back water station. The daily integrals for each station must be considered equivalent within the errors of estimation. At Notigi, the mainstem station had nearly four times the biomass of the bay station, and the optimum production was similarly four times greater. However, light extinction at the mainstem station was twice that in the bay thus the daily integral was only twice that of the bay. This bay probably has very poor exchange with the mainstem basin, and it also has a very restricted local drainage. Both factors contribute to its low productivity. At Wapisu the back water station had nearly three times the biomass of the mainstem, but the mainstem station had a higher optimum production indicating that the algae in the bay were in or approaching a senescent condition. Once again the daily integrals were essentially identical. Apparently the turnover time in these lakes is sufficient to break down patterns of production strictly relatable to the river discharge. Local differences still apply related to restricted circulation imposed by basin morphology, but one can't generalize about stations receiving full river discharge and those not.

The outlet of Rat Lake had a higher algal biomass and a higher optimum productivity although the daily integral was lower because of a higher extinction coefficient. Residence within the lake apparently has allowed growth processes to increase the algal biomass which supports earlier statements concerning mean algal biomasses increasing downstream. This supporting evidence however is tempered by the recognition of the previous paragraph that quite remarkable horizontal heterogeneity exists in this lake.

The Mynarski station on 30 August had the second highest biomass observed in the study area and the highest optimum productivity and daily integral observed in the study area. This again demonstrates that in the Rat basin high discharge is not required to ensure a good level of nutrient supply. The Mynarski lakes have the longest exchange time (greater than one year) of any lakes studied in the basin yet they appear to be the most productive lakes in the basin or the entire study area for that matter.

On the second sampling trip to the mainstem stations, all the stations with the exception of Wapisu showed substantially lower production (optimum rate and daily integral) than on the earlier trip. Wapisu was also the only station to have a higher biomass than the previous trip while Mynarski had approximately the same biomass as previously. Even on Wapisu the replacement rate, i.e. 10% of biomass divided by rate of production at optimum is very much slower at Wapisu on the second trip as compared to the first, 14 hours versus 8.8 hours. The decline at all stations is a response to declining solar radiation and temperature through the autumn. As for the average phytoplankton biomass (Figure 4.1) the daily integral of production and the production at optimum light increase downstream on each trip.

In summary the Rat River lakes per unit of area exhibit production equivalent to or exceeding that of Southern Indian Lake and the lower Churchill lakes. Nutrient loading rates (Cleugh 1974) would predict a eutrophic status for most of the lakes and the algal biomass and production figures are consistent with a mesotrophic to eutrophic classification whereas Southern Indian was considered oligotrophic to mesotrophic by the same criteria. The optimum production rates generally exceed by 50% the optimum values observed in Southern Indian indicating a more nutrient-rich environment, but the light extinction coefficients are generally higher on the Rat system so that the values for integral production are equivalent to or somewhat higher on the average than Southern Indian Lake. Productivity in the Rat basin lakes is not simply related to high discharge and low turnover as on the Churchill system, and this is probably the result of basins soils releasing nutrients more rapidly than in the Churchill drainage. High discharge is not required to maintain an adequate supply of nutrients.

4.3. Impact of impoundment and diversion:

Diversion of the Churchill River and impoundment at Notigi will drastically change the hydrology and ecology of the Rat-Burntwood River and its lake. All the lakes above Notigi with the exception of the eastern-most of the Mynarski Lakes and Suwanee Lake will be united at a common water level (most probably 850 ft). Approximately 70% of the reservoir area will be underlain by flooded materials. The residence time of water in the new reservoir will be about two months based on the total volume, but more likely the exchange time for the Churchill River plume will be much less as was observed in Southern Indian Lake. Back water areas will likely have quite different chemical and ecological conditions than the part of the reservoir receiving direct Churchill River flow. The extreme shoreline development of the new reservoir will emphasize this horizontal heterogeneity basically imposed by the high discharge of the river. The mainstem portion of the reservoir, in the long term, will exhibit productivities similar to those presently found in Southern Indian Lake which are nearly as high as those presently found in the Rat River lakes. Immediately after diversion, however, Churchill River water entering the new reservoir will have its transparency reduced by silts in clays from shoreline erosion so that initially productivity in the mainstem will be lower than that presently occurring in Southern Indian Lake or the Rat River lakes. The shallow upper portion of the reservoir immediately below the diversion canal will likely have especially severe turbidity problems in the first few years after diversion. Much of the coarser sand and silts will be retained within the reservoir so that some clarification is expected between Issett and Notigi, but particles of clay size will pass through the system, and add to the very severe turbidity problems expected below the reservoir (Underwood-McClellan 1973).

In small protected backwater bays in the new reservoir where stro waves can't develop because of inadequate fetch the primary affect on water quality will be leaching of nutrients and humic materials from soi and vegetation. Although this nutrient leaching leads to an initial increase of primary production in more southern reservoirs there is reason to believe that this may be offset in northern reservoirs by the humification of waters (see the discussion of Kettle Reservoir below). In larger more exposed bays with sufficient fetch to induce strong wave action shoreline erosion will proceed rapidly with removal of trees bank undercutting, and slumping adding debris and suspended materials in large amounts to the water. Turbidity will be a problem in these areas initially and for some time to come (much greater than ten years) because of the thick clay overburden in the Rat basin. Swan Bay in Southern Indian Lake is perhaps the best example of the time it requires to stabilize a shoreline in thick clay overburden. Very low production because of light limitation can occur in these areas. Similar affects on production can be predicted for Wuskwatim Reservoir.

Downstream of the Notigi Reservoir greatly reduced production wil occur as channel cutting under the new high discharge (10x the present average) leads to very high turbidities (Underwood-McClellan 1973).

Algal production will be very low because of light limitation and high flushing rates in the lakes will not allow clarification. Algal populations will decline rapidly below the reservoir to levels even lower than those presently found in the Burntwood (Figure 4.1). Two of the most productive lakes Wapisu and Wuskwatim will have great reductions in primary production. In this case, building a reservoir at Wuskwatim would lead to substantial increases in algal production o an areal basis. The reservoir would increase the residence time and al coarser suspended materials to settle. The clarification would reduce light limitation and permit higher primary production.

Little in the way of practical mitigation can be suggested for the new Notigi Reservoir. Timber clearing might eliminate or reduce t humification problem but aggravate problems of shoreline erosion. Leaving timber in place can slow down shoreline erosion, but aggravate humification. Research into these questions is desparately needed in view of the tremendous expense that clearing can add to reservoir construction and maintenance. The Fisheries-Limnology sector will recommend experimental clearing of selected areas and intensive monitoring to seek answers to these questions. Information developed from such research could lead to rationale clearing criteria to protect water quality in lakes to be flooded in the future or improve water quality in existing reservoirs.

5. THE NELSON RIVER AND ITS RESERVOIRS

The portion of the Nelson River considered in this report the stretch from and including Cross Lake to Kettle Reservoir ne Gillam (see Figure 1.1). Nelson station 1 is above Kelsey Dam, the outlet to Cross Lake, Nelson 2 is just below Kelsey Reservoi Nelson 3 is at Split Lake, Nelson 4' is above Kettle Reservoir o the Nelson River plume, Nelson 5 is below Kettle Dam, and statio is in a bay of Kettle Reservoir off the Nelson River plume backi into what was formerly Moose Creek. These stations were monitor phytoplankton in 1972 and 1973 and the results are given in Figu and 5.2. On 26 September 1973 six stations for primary producti made on the Nelson. The reservoirs on the Nelson are the northe most in Manitoba and the physiography is similar to that of much of the study area especially Southern Indian Lake. Study of pre conditions in these reservoirs offers the best available insight probably impact of the present development. The utility of this however, is hampered by the lack of any pre-impoundment data.

5.1. The seasonal cycle of phytoplankton:

In both 1972 and 1973 the maximum algal biomasses observed the Nelson River system were well below those observed on the Ch and Rat-Burntwood River systems. In 1972 the maximum value obse 1,000 $mg.m^{-3}$ occurred at Moose Creek, but the high value at the was due to a surface bloom of blue-green algae. At 4 m depth on mg.m^{-3} of algal biomass were found. Aside from this one value the highest observed was 650 mg.m^{-3}. These biomasses indicate very low net primary production in the river and its lakes. The algal flora is quite diverse with cyanophytes, diatoms, and cryptophytes increasi during algal maxima. Moose Creek has a distinctive algal flora in th cryptophytes tend to predominate there most of the time. There is no tendency as in the other river systems for one group to increase dram and cause the algal maxima. Periodicity of standing crops is also subdued compared to the other river systems. There is a tendency for a summer maxima at most stations in 1972 but the maxima are only two three times the minima for the open-water season. In fact the mean summer values are very similar to the under ice values in December. This contrasts sharply with the situation in Southern Indian Lake (Hecky _et al_. 1974) where summer maximum values were 10 to 30 times the winter values. There is a tendency for mean summer values to decl downstream in 1972 but the pattern was not clearly reproduced in 1973

In 1973 higher biomasses (approximately double) were recorded at all stations, but the maxima were still well below those recorded in the Churchill and Rat-Burntwood systems. There was a fall maximum at all mainstem stations while Moose Creek had a spring maximum as it did in 1972. Diatoms and chrysophytes occur at Moose Creek only duri this spring period. Cryptophytes dominated Moose Creek throughout th year, and this is the only location in the whole study area where Cryptophytes are abundant. The higher biomasses in 1973 correlate wel with the evidence for more severe nutrient depletion (especially nitra nitrogen) in 1973 as opposed to 1972 (Cleugh 1974) but the causation f the higher production is obscure. In general the measured nu concentrations are similar to or somewhat higher than those m in the Rat-Burntwood and Churchill Rivers, and the lower net in the Nelson is probably due to the higher turbidity and low transparency in the Nelson system (Cleugh 1974). Except for after ice-out when the water is somewhat clearer the Secchi d parency never exceeds one meter except at Moose Creek (statio at Moose Creek light penetration is quite low compared to the river systems (see below).

5.2. Primary production:

At the time of the primary production experiments Sipi (behind Kelsey Dam) had the highest algal biomasses with near the standing crop at Kettle Reservoir (Table 5.1). However, chlorophyll values were similar in both reservoirs as were th for production at the light optimum (P_{opt}) excluding the Moos station (4). This indicates that the algae in Kettle Reservo were much more photosynthetically active per unit of biomass. predominance of blue-green algae and the low activity at Kels suggests that much of the algal biomass may be a senescent su of blue-greens. The low chlorophyll to biomass ratio (0.0018 suggests nutrient depletion (Healey 1973). The daily integra production is broadly similar for each. The daily integral o production is comparable to those observed on the lower Churc lakes and in the less productive regions of Southern Indian L Creek, the inundated area, had a substantially lower optimum

daily integral than the mainstem stations despite having a similar
standing crop.

5.3. Impact of impoundments - the Moose Creek station:

When the Nelson River was impounded behind Kettle Reservoir
1969 a large area of flooded timber was formed as the water backed
to the north in the former Moose Creek drainage. This area today
chemically distinct from the mainstem portion of the reservoir (Cl
1974). The chemical differences in major constituents are attribu
to the influence of Moose Creek drainage on this area, but the dif
in minor constituents, especially nutrients, are a result of inund
Other significant differences found by Cleugh (1974) between Moose
and mainstem Nelson stations involved Secchi disc transparency and
oxygen concentrations. Secchi disc visibility at Moose Creek was
always between 1.5 and 2.5 m while mainstem stations were always l
than 1.0 m and usually less than 0.5. All the mainstem stations s
reduced oxygen concentrations before and immediately after ice-out
depletion at Moose Creek was greater with oxygen concentrations fa
to less than 20% of saturation. While all mainstem stations were
oxygen saturated through the open-water season, Moose Creek was ne
fully saturated indicating a substantial oxygen demand at all seas

As noted above the phytoplankton populations at Moose Creek
also distinctive. Cryptophytes predominate throughout the year wi
other algal groups, diatoms and chrysophytes, being prominent only
the spring maximum. Although standing crops exceed those of mainst
stations at Kettle Reservoir and the chlorophyll values are similar
productivity at optimum light is less than one-half that of the mai

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indicating that the algae are not very active. This low
compounded with a light extinction coefficient higher th
stations yields a daily integral of production only 30%
mainstem stations. The apparent discrepancy between Sec
visibility and light extinction measured with a photocel
in the parameters being measured. The Secchi disc measu
of all light and especially the extinction of image-form
scattered). When turbidity is high, light scattering is
the Secchi disc image is rapidly obliterated. However,
not absorption as the scattering rapidly becomes random
great deal of forward scattering. Therefore, it is poss
both a high Secchi disc value and high light extinction
A similar phenomena was found in the various regions of
Lake. The high extinction and dark brown color of Moose
due to humification (leaching of organic compounds from
soils) after flooding. One estimate of the greater amou
organic compounds at Moose Creek can be seen in Table 5.
organic carbon concentrations in Moose Creek, 1,365 µmol
75% higher than the mainstem stations. The difference i
properties can be explained by the concentrations of tot
solids given in Table 5.2. Moose Creek has trace concen
the mainstem stations have 3-9 $mg.l^{-1}$.

Experience in new reservoirs in southern latitude
inundated soils and vegetation are an additional source
after flooding. The paradigm for development of biologi
in a new reservoir is that initially a level of producti

the pre-impoundment level occurs which, after a period of years, declines to a level somewhat below the pre-impoundment production. Enhanced primary production because of the nutrients provided by inundation has usually been invoked to explain this. As flooded materials decay or are buried by sedimentation, primary production declines to pre-impoundment levels; or, because of the greater volume of the reservoir, to somewhat lower levels. It must be emphasized that this is an hypothesis and the number of cases in which it has been tested is very small especially in northern latitudes. The experience at Moose Creek defies this simple model.

Nutrient concentrations at Moose Creek are elevated, often extremely so. In Table 5.2 nutrient data, including nitrite, ammonia, and phosphate (soluble reactive phosphate) parameters not routinely measured by Cleugh (1974), are summarized. For every soluble nutrient except total dissolved nitrogen (which is somewhat unreliable analytically, M.P. Stainton, personal communication) the Moose Creek station has much higher concentrations. At Moose Creek nitrate levels are 20x mainstem stations, nitrite is only found there, ammonia is 3-9x mainstem stations, phosphate is 12-32x mainstem stations, and total dissolved phosphorus is 3-6x. It is noteworthy that all the Nelson River stations had appreciable ammonia concentrations while ammonia was not detectable in either the Rat-Burntwood or the Churchill River lakes. Decaying, inundated vegetation is likely responsible for maintaining these ammonia concentrations. Clearly nutrients are being leached from the flooded materials, but the nutrients are not being utilized by the algae. Phosphate uptake experiments conducted at Moose Creek, other Nelson stations, and stations on

Southern Indian Lake by D.W. Schindler (personal communication) revealed that Moose Lake had the lowest uptake of any station observed.

Hypotheses which could account for the above discrepancies include: 1) algal populations are nutrient limited either due to scarcity of trace elements or major nutrients in chemical forms available to the algae; and/or 2) there is a toxic principle leached from decaying vegetation and soils which inhibits algal growth. Cryptophytes in Canadian waters tend to be most abundant in nutrient-poor Shield waters (Kling and Holmgren 1972). The predominance of this algal group in Moose Creek may be indicative of poor nutrient conditions. It is possible that one or all the major nutrients are in chemical forms unavailable to algae although they are analytically available. It is also likely that trace metals such as iron may be unavailable to the algae. Humic acids have been shown to be able to sequester phosphate and metals, and humification following impoundment may make acquisition of these necessary nutrients difficult and lead to "starvation in the face of plenty". Alternatively some of the complex organic compounds present in vegetation, e.g. phenolic compounds, are known to have toxic effects on many organisms. It is possible that such compounds are present in solution in Moose Creek, and they are actually inhibiting algal growth.

Research into the effects of humification on nutrient availability and into the organic hydrogeochemistry of new reservoirs is required before any generalization about the developmental course of primary production in northern reservoirs can be made. This limited survey has raised serious questions about the widely accepted paradigm of reservoir development. Although analytically detectable major nutrients do increase substantially the utility of these nutrients to algal populations appears doubtful. The role of micronutrients has not been investigated and these may be a problem in flooded areas. Until further research is forthcoming, it is safest to base predictions of the future primary productivity of Notigi Reservoir and other reservoirs on the Burntwood and Nelson Rivers on the analogy offered by Kettle. Flooded areas will likely have primary productivity lower than the pre-existing lakes while the mainstem portions of the new reservoirs will be similar to pre-impoundment levels in upstream lakes.

6. SUMMARY

The mainstem portion of the lower Churchill lakes exhibit the same magnitude and periodicity of algal standing crops as the northern region of Southern Indian Lake. There is a general decline of seasonal average algal biomass through the lakes and decreasing transparency is likely responsible. The backwater areas of the lakes have distinctly different algal populations and much lower algal standing crops and primary production. The mainstem portions of the lake receive imported biomass from Southern Indian Lake which maintains the higher level of primary production in the Churchill plume as compared with back water areas. Without mitigation measures primary production per unit area will likely fall to two-thirds its present level and total lake production would decline even further because of the loss of area on these lakes as a result of diversion. Construction of weirs at the outlets of the lakes and guaranteeing a higher minimum discharge will largely offset these negative aspects and maintain total lake primary production nearer its present level.

The Rat-Burntwood Lakes on the average have higher standing crops than the Churchill River lakes including Southern Indian Lake. The periodicity is also different with a tendency to a summer maximum constituted largely of blue-green algae. The primary productivity of the lakes on a per unit area basis is similar to or somewhat higher than Southern Indian Lake. There is not the clear delineation between on-plume and off-plume production which characterizes the Churchill River lakes. The longer residence times in the Rat-Burntwood lakes permits better mixing and the predominantly clay soils of the drainage may supply more nutrients per unit of watershed area weathered than the Churchill basin. After diversion and impoundment, the mainstem portions of the reservoir will have productivities per unit area comparable to the northern region of Southern Indian Lake although initially these may be depressed because of higher turbidities than Southern Indian Lake. Backwater areas off the mainstem will exhibit productivities below that of the mainstem portion. Humification and/or high turbidities will be the primary problems. Although average primary production per unit area in the new reservoir will be lower than in the present lakes, the large increase in area will result in a greater total production for the system. Lakes between Notigi and Thompson will have severely degraded water quality because of channel erosion. The productivity of these lakes will be partially restored when and if the Wuskwatim Reservoir is built. Little in the way of effective mitigation can be suggested at this time.

The results of primary production experiments on existing Nelson River reservoirs appear to confound the commonly accepted model for the time course of primary production levels in new reservoirs. Abundant nutrients are analytically present in flooded areas probably from leaching and oxidation of organic materials. However, the algae are not utilizing these nutrients. Several plausible explanations exist, but only future research will resolve the apparent paradox.

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PERSONAL COMMUNICATION

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Table 3.1. Algal biomass, dominant algal group, chlorophyll, light extinction coefficient, and the results of primary productivity experiments of 25 September 1973.

	Biomass (mg.m^{-3})	Dominant Group (%)	Chlorophyll (mg.m^{-3})	Extinction Coefficient* (m^{-1})	P_{opt} mg C.m^{-3}hr^{-1}	Daily Integral mg C.m^{-2}.da^{-1}
Partridge Breast Lake	3,660	Diatomeae (78)	2.4	1.2	11	480
Wood Lake	1,880	Cyanophyta (40)	3.7	0.81	5.7	340
Northern Indian Lake (mainstem)	2,660	Diatomeae (71)	3.1	1.8	10	490
Northern Indian Lake (bay)	1,240	Chrysophyceae(36)	2.5	1.4	6.5	250
Fidler Lake (mainstem)	2,520	Diatomeae (67)	3.8	1.5	10	430
Fidler Lake (bay)	943	Chrysophyceae(35)	2.8	1.0	4.9	170

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* Calculated from regression of extinction coefficients on Secchi disc for all Churchill River stations.

Table 4.1. Algal biomass, dominant algal group, chlorophyll, light extinction coefficient, and the results of primary productivity experiments of August 30-31 and September 24, 1973. P_{opt} = volumetric productivity at the optimum light intensity, and daily integral is the areal productivity achieved on a cloudless day.

	Biomass ($mg.m^{-3}$)	Dominant Group (%)	Chlorophyll ($mg.m^{-3}$)	Extinction Coefficient (m^{-1})	P_{opt} mg $C.m^{-3}hr^{-1}$	Daily Integral mg $C.m^{-2}.da^{-1}$
Pemichigamau (mainstem; 30-8-73)	5,820	Cyanophyta (59)	10.1	2.1	19	440
Pemichigamau (bay; 30-8-73)	4,040	Cyanophyta (51)	5.8	2.9	27	470
Pemichigamau (mainstem; 24-9-73)	1,120	Chrysophyceae(30)	2.5	1.8	9.5	250
Rat (mainstem; inlet; 31-8-73)	4,190	Cyanophyta (54)	8.8	1.2	24	1,100
Rat (mainstem; outlet; 31-8-73)	5,330	Cyanophyta (70)	9.6	1.5	27	890
Rat (mainstem; inlet; 24-9-73)	-	-	3.1	1.1	17	830
Notigi (mainstem; 30-8-73)	4,410	Cyanophyta (59)	10.8	1.5	42	1,300
Notigi (bay; 30-8-73)	1,250	Cyanophyta (34)	6.8	0.69	11	670
Notigi (mainstem; 24-9-73)	3,290	Cyanophyta (46)	4.4	1.6	24	700
Wapisu (mainstem; 31-8-73)	3,710	Cyanophyta (86)	11.2	1.7	42	970
Wapisu (bay; 31-8-73)	10,810	Cyanophyta (86)	13.2	2.6	31	920
Wapisu (mainstem; 24-9-73)	5,680	Cyanophyta (50)	3.3	1.3	40	1,500
Mynarski (30-8-73)	6,640	Cyanophyta (55)	11.2	1.3	70	2,800
Mynarski (outlet; 24-9-73)	6,430	Diatomeae (59)	7.2	1.2	20	860

Table 5.1. Algal biomass, dominant algal group, chlorophyll, light extinction coefficient, and the results of primary productivity experiments of 26 September 1973.

	Biomass (mg.m^{-3})	Dominant Group (%)	Chlorophyll (mg.m^{-3})	Extinction Coefficient (m^{-1})	P_{opt} mg C.m^{-3}hr^{-1}	Daily Integral mg C.m^{-2}.da^{-1}
Sipiwesk Lake (Kelsey)	1,500	Cyanophyta (57)	2.7	1.0	11	380
Nelson 2 (below Kelsey)	1,370	Cyanophyta (62)	2.1	1.2	13	550
Split Lake	-	-	3.8	1.9	15	370
Kettle Reservoir (mainstem) St. 4'	674	Cryptophyceae(36)	4.5	1.3	12	500
Kettle (inundated bay) St. 4	898	Cryptophyceae(96)	3.0	1.8	5	140
Nelson 5 (below Kettle)	700	Cryptophyceae(35)	2.5	1.4	13	470

Table 5.2. **Nutrients and other selected chemical parameters for Nelson River waters on 26 September 1973. NO_3-N = nitrate nitrogen; NO_2-N = nitrite nitrogen; TDN = total dissolved nitrogen; SN = suspended nitrogen; PO_4-P = phosphate phosphorus; SP = suspended phosphorus; DIC = dissolved inorganic carbon; DOC = dissolved organic carbon; SC = suspended carbon; Si = Silicon; TSS = total suspended solids.**

	NO_3-N $\mu g.1^{-1}$	NO_2-N $\mu g.1^{-1}$	NH_3-N $\mu g.1^{-1}$	TDN $\mu g.1^{-1}$	SN $\mu g.1^{-1}$	PO_4-P $\mu g.1^{-1}$	TDP $\mu g.1^{-1}$	SP $\mu g.1^{-1}$	DIC μmole	DOC μmole	SC $\mu g.1^{-1}$	Si $mg.1^{-1}$	TSS $mg.1^{-1}$
Sipiwesk Lake	5	n.d.*	27	56	91	0.5	12	14	1,860	162	610	0.91	5
Nelson 2 (below Kelsey)	4	tr **	8	316	79	2.5	24	13	1,780	892	480	1.0	3
Split Lake	5	n.d.	13	53	60	6.5	17	20	1,926	738	570	1.2	9
Kettle Reservoir (mainstem)	4	n.d.	19	299	66	2.5	23	14	1,790	107	510	1.3	5
Kettle (inundated bay)	107	8	73	183	35	74	79	12	1,810	1,365	270	1.7	tr

* n.d. = not detectable

** tr = trace

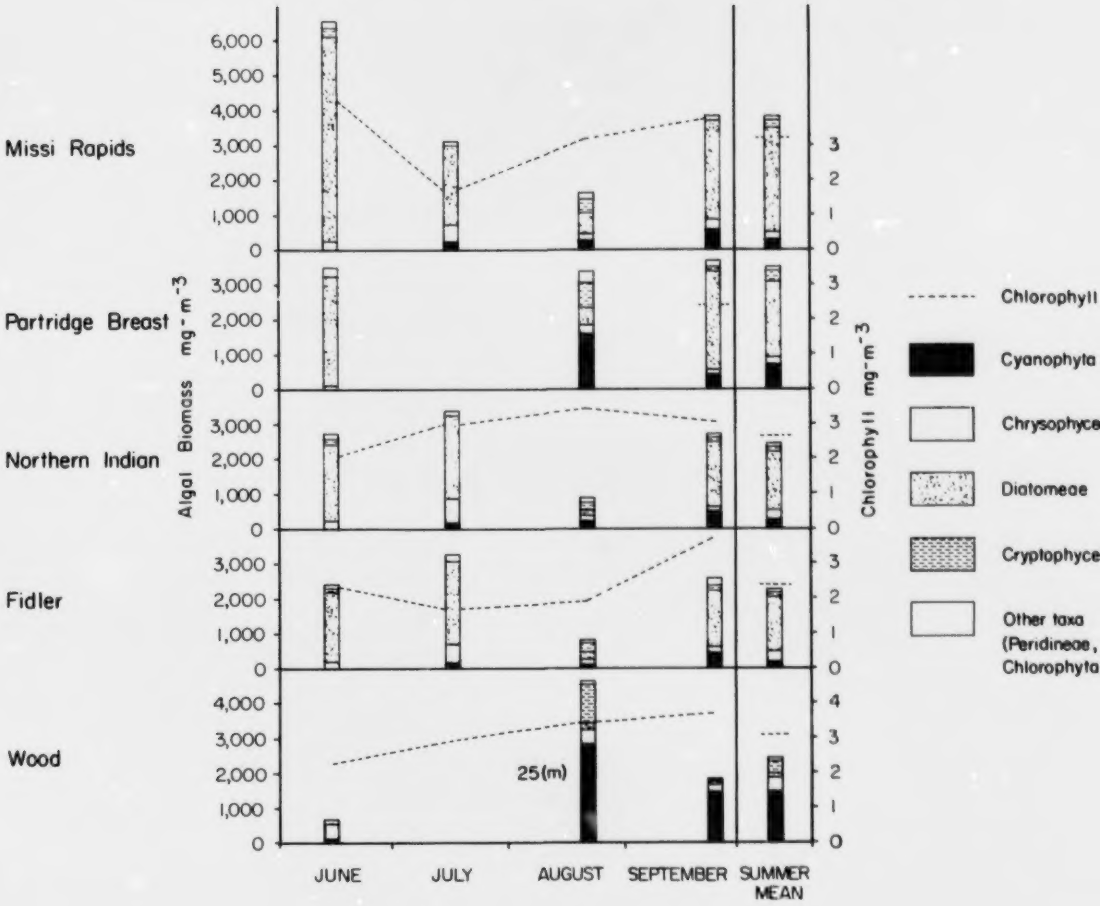
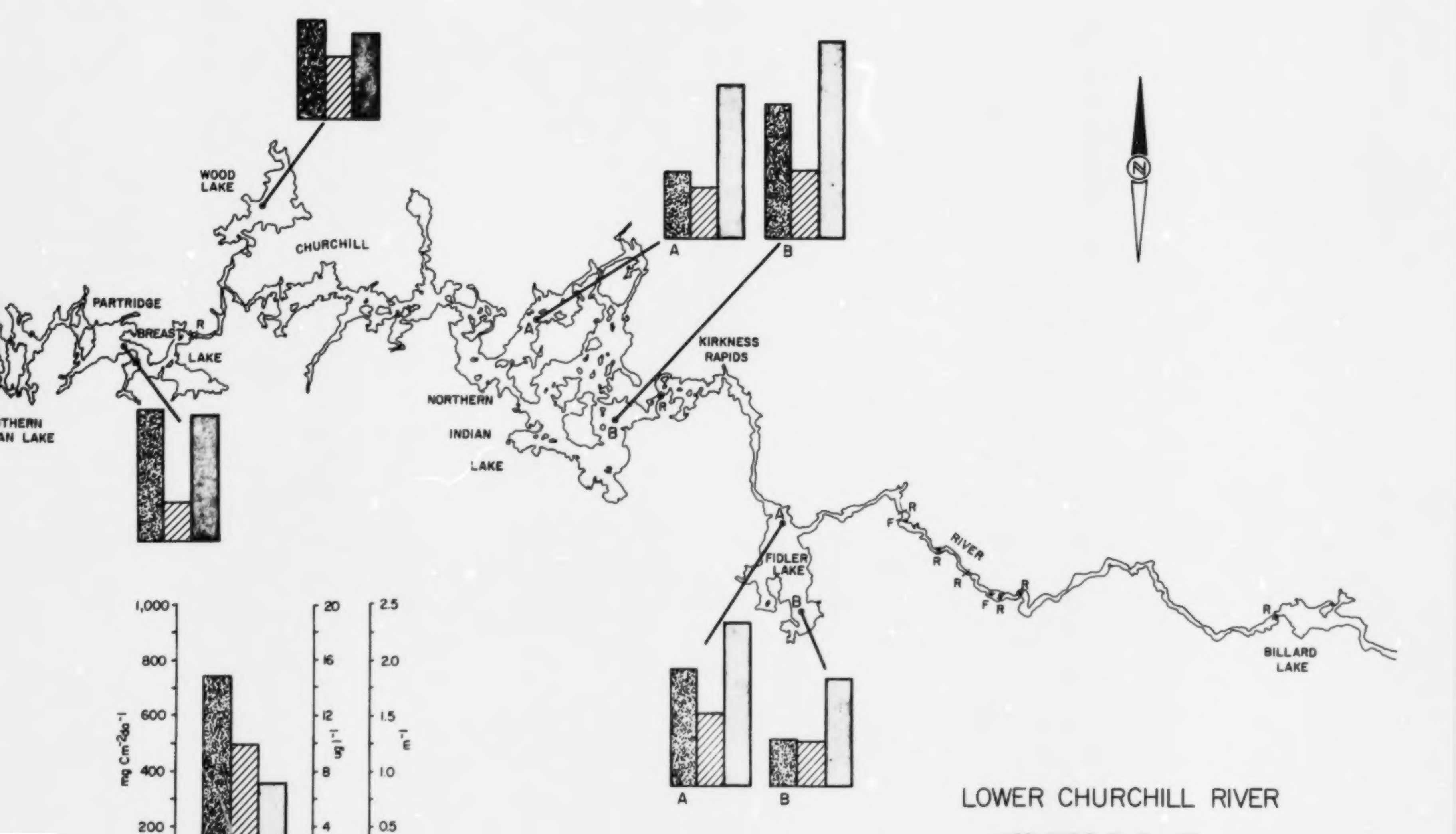


Fig. 3.1 Algal biomass, taxonomic composition, and chlorophyll for the lower Churchill lakes during the summer of 1973

uglenophyta,


WOOD LAKE
CHURCHILL
PARTRIDGE
BREAST
R
LAKE
THERN
AN LAKE
A
B
KIRKNESS RAPIDS
NORTHERN
INDIAN
LAKE
R
A
FIDLER LAKE
B
F
R
RIVER
R
R
F
R
R
R
BILLARD LAKE
A
B
LOWER CHURCHILL RIVER
mg C m⁻²d⁻¹
1,000
800
600
400
200
µg l⁻¹
20
16
12
8
4
m⁻¹
2.5
2.0
1.5
1.0
0.5

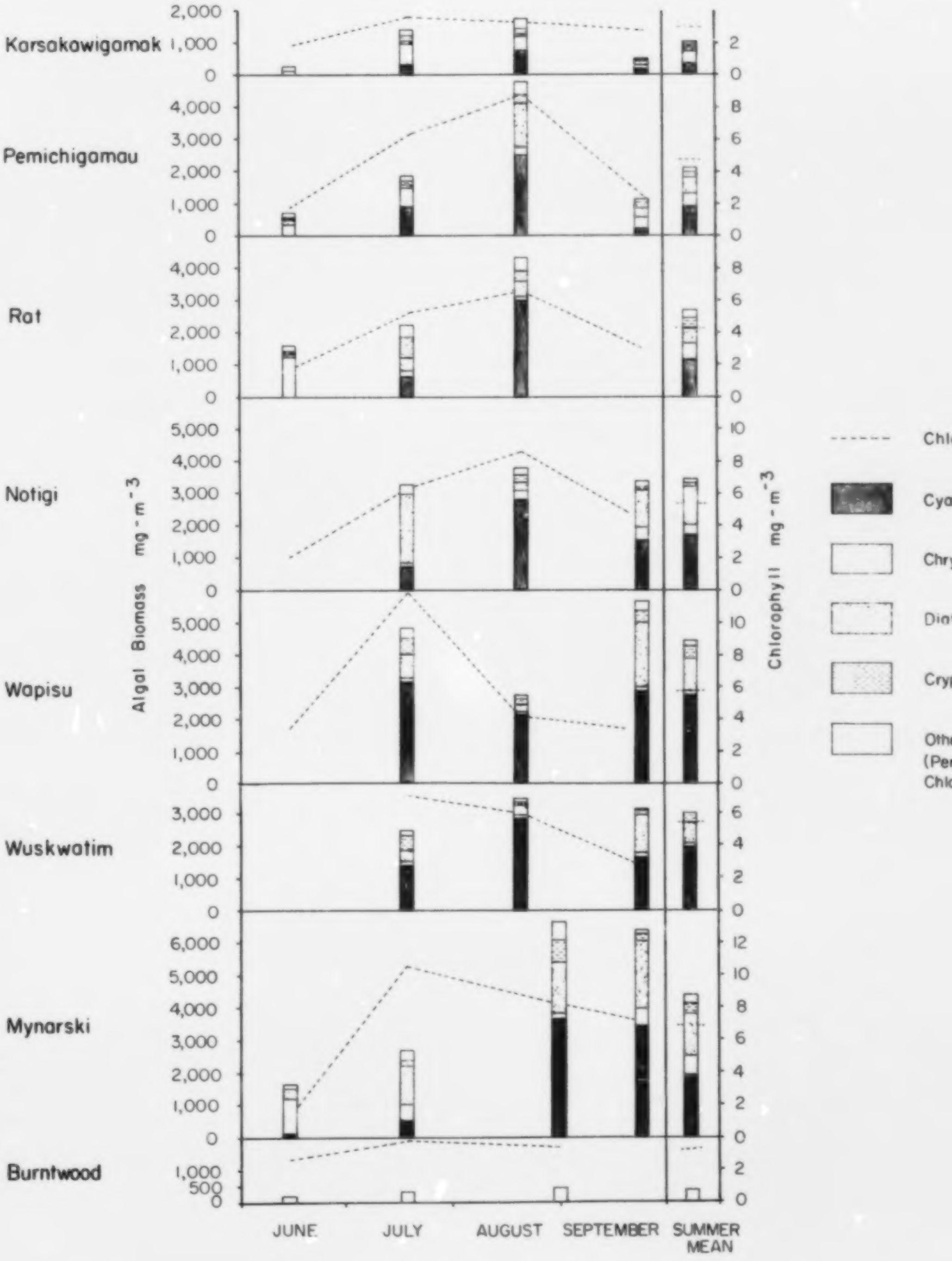


Fig. 4.1 Algal biomass, taxonomic composition, and chlorophyll for some Rat-Burntwood lakes during the summer of 1973.

5

ophyll

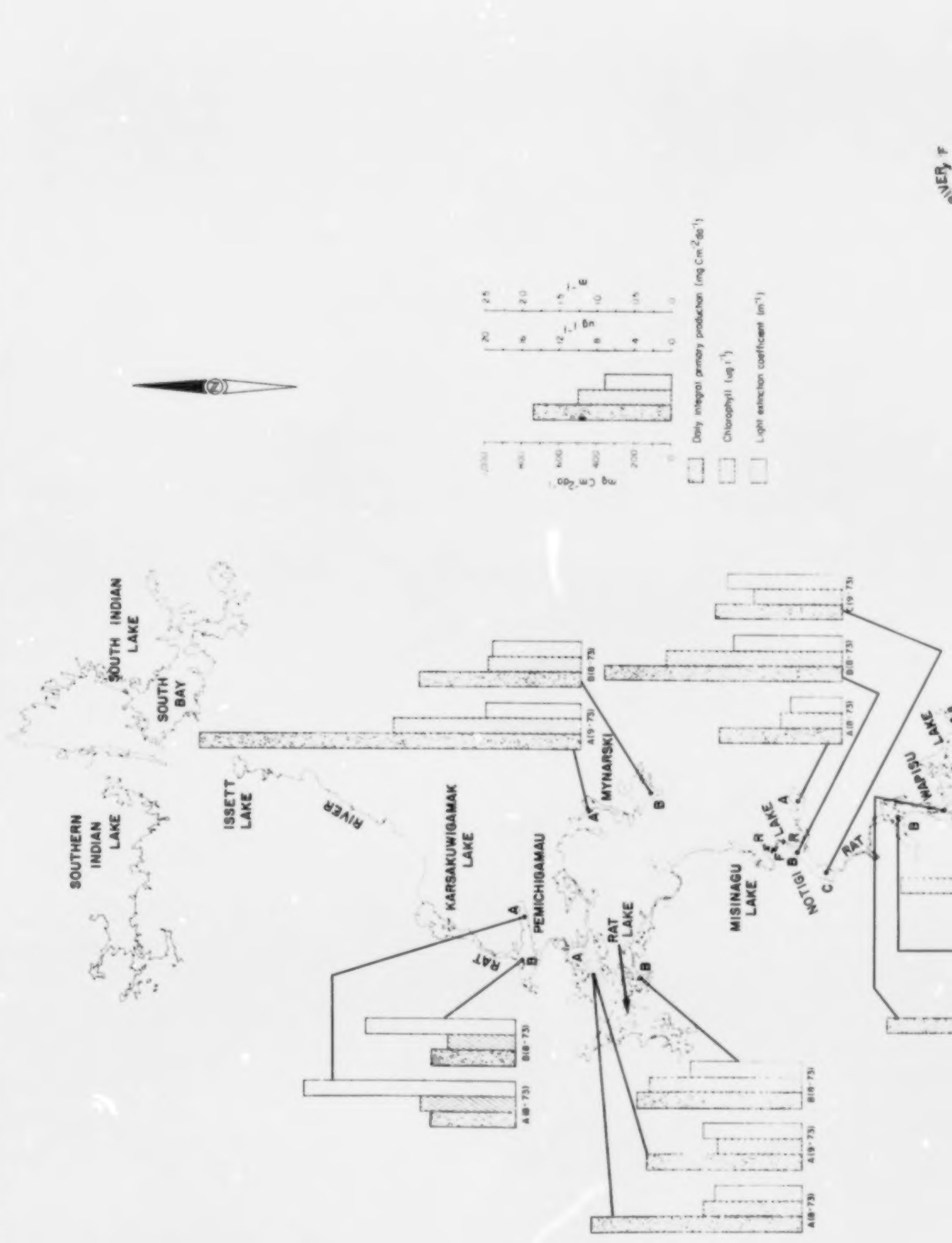
ophyta

ophyceae

meae

ophyceae

taxa
ineae, Euglenophyta,
ophyta)



N
mg C m⁻² da⁻¹
0
200
400
600
800
1000
ug l⁻¹
0
4
8
12
16
20
m⁻¹
0
0.5
1.0
1.5
2.0
2.5
Daily integral primary production (mg C m⁻² da⁻¹)
Chlorophyll (ug l⁻¹)
Light extinction coefficient (m⁻¹)
SOUTHERN INDIAN LAKE
SOUTH INDIAN LAKE
SOUTH BAY
ISSETT LAKE
RIVER
KARSAKUWIGAMAK LAKE
PEMICHIGAMAU
RAT
MYNARSKI
RAT LAKE
MISINAGU LAKE
NOTIGI
LAKE
WAPISU LAKE
RAT
RIVER
A
B
C
R
A(9-73)
B(8-73)
A(8-73)

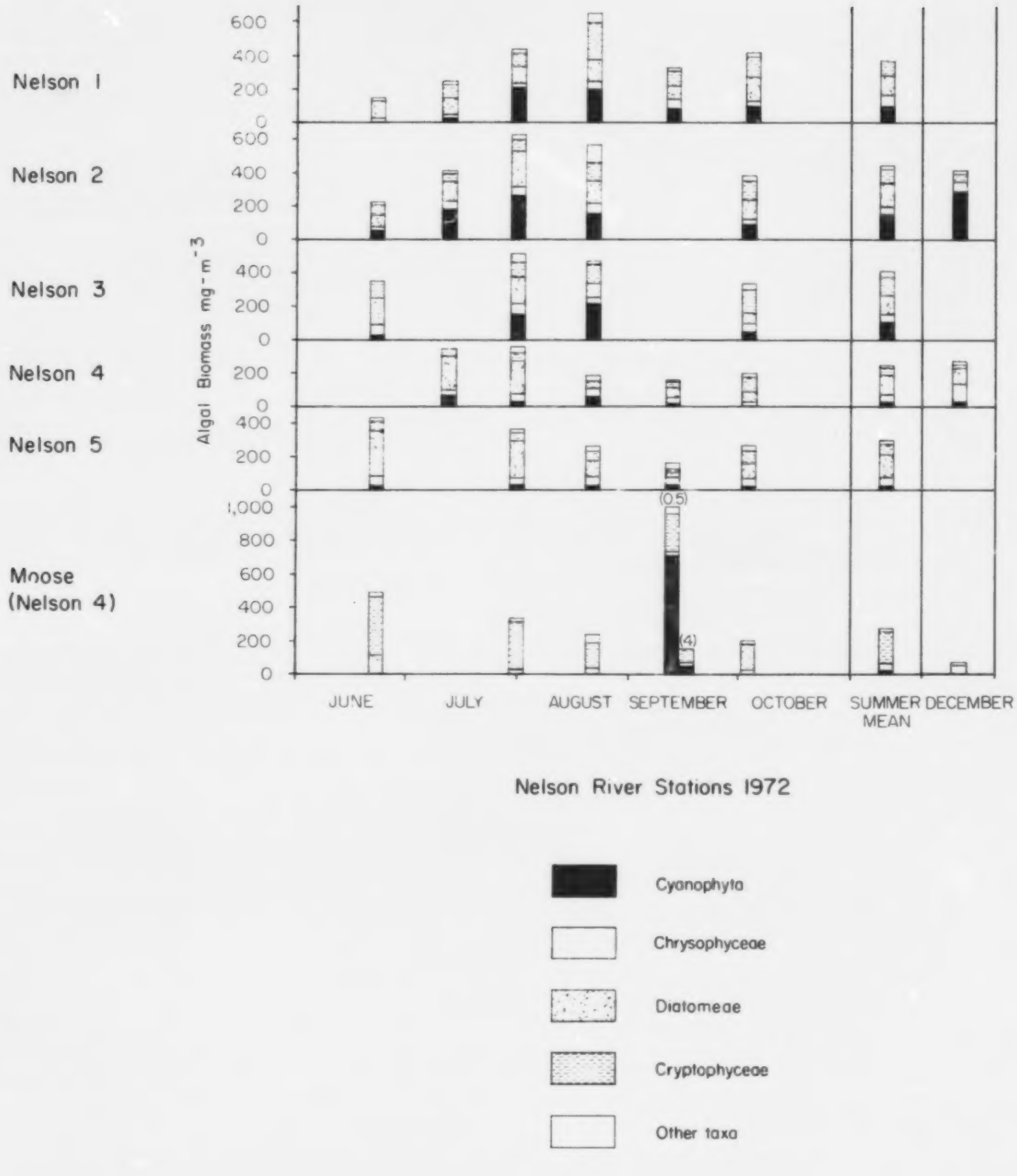


Fig. 5.1. Algal biomass and taxonomic composition for the Nelson River during 1972.

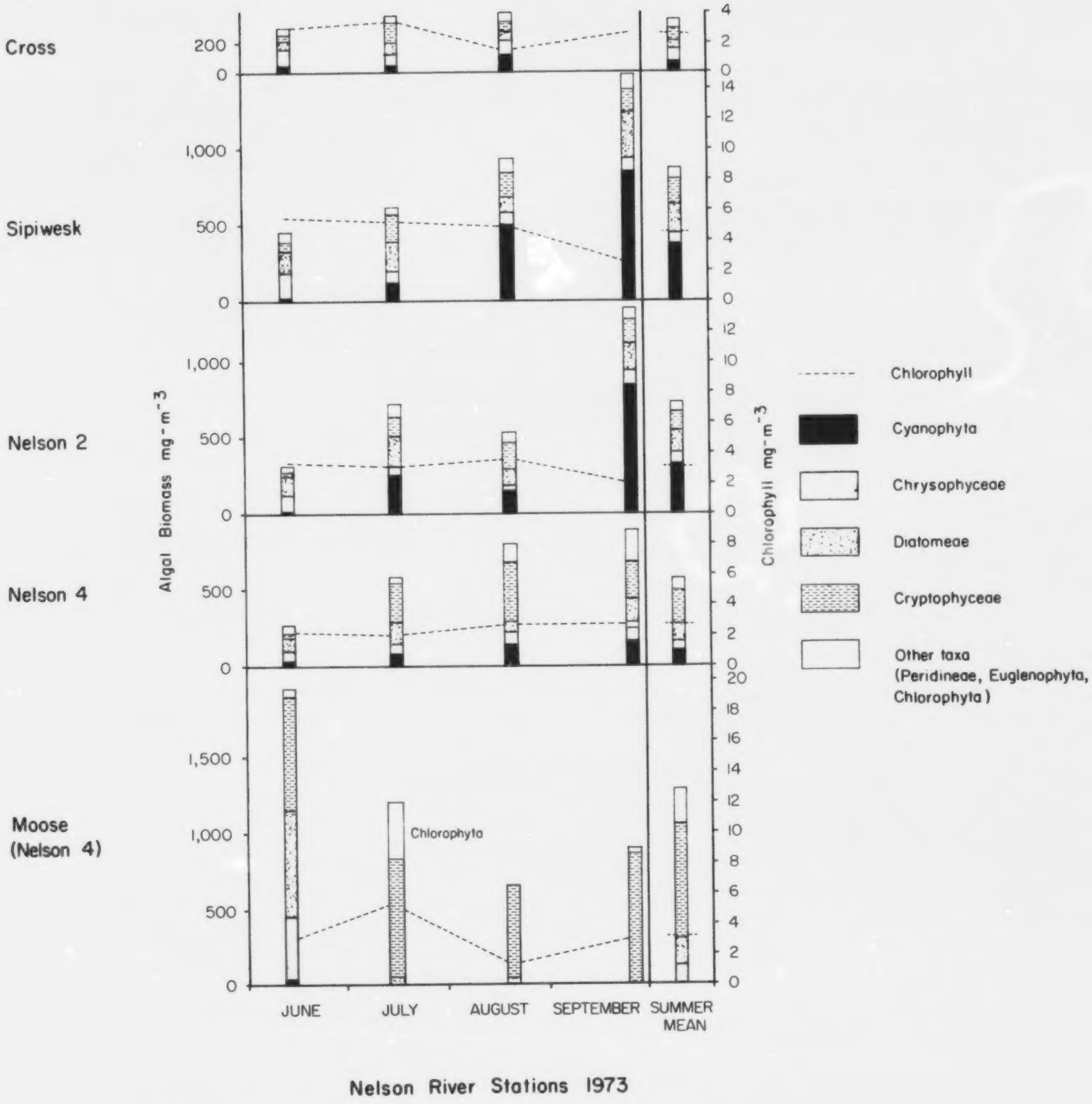


Fig. 5.2. Algal biomass, taxonomic composition and chlorophyll for Nelson River stations during the summer of 1973.

APPENDIX 5 - VOL. 2 - G

CRUSTACEAN PLANKTON OF LAKES ON THE LOWER CHURCHILL RIVER AND RAT-BURNTWOOD RIVER SYSTEMS

CRUSTACEAN PLANKTON OF LAKES ON THE LOWER CHURCHILL RIVER AND RAT-BURNTWOOD RIVER SYSTEMS

by

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Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
August, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

The purpose of this study is to characterize the zooplankton of the lakes on the lower Churchill and Rat-Burntwood River systems before the diversion of the Churchill River to the Nelson River is completed, and to predict the impact of the diversion on the zooplankton. This study also provides the background data for a more detailed, after-diversion study the purpose of which would be to verify the predictions and to increase our capacity to predict the impact of similar environmental manipulations in the future.

Four lakes on the lower Churchill River (Partridge Breast, Wood, Northern Indian and Fidler) and seven lakes of the Rat-Burntwood River system (Karsakuwigamak, Pemichigamau, West Mynarski, Rat, Notigi, Wapisu and Wuskwatim) were sampled during the summer months of 1973. The lower Churchill lakes (except Wood Lake) have at present a very high flow rate, and correspondingly a very short water exchange time. After the diversion, when the flow rate will be reduced from the present 30,000 cfs to about 5,000 cfs, the water exchange time could be lengthened proportionally, i.e. about six times, assuming that the lakes could be maintained in their present areas. However, due to the reduced flow the area and the volume of the lower Churchill Lakes will be reduced proportionally so that water exchange time in these reduced lakes will remain very similar to the present one

Following the diversion, the Rat-Burntwood River system will have a significantly increased flow rate and the water exchange time in lakes of this system will shorten significantly.

By comparing these two groups of lakes with their different water

Figure 1. The location of Rat-Burntwood River system lakes (A) and lower Churchill River lakes (B).

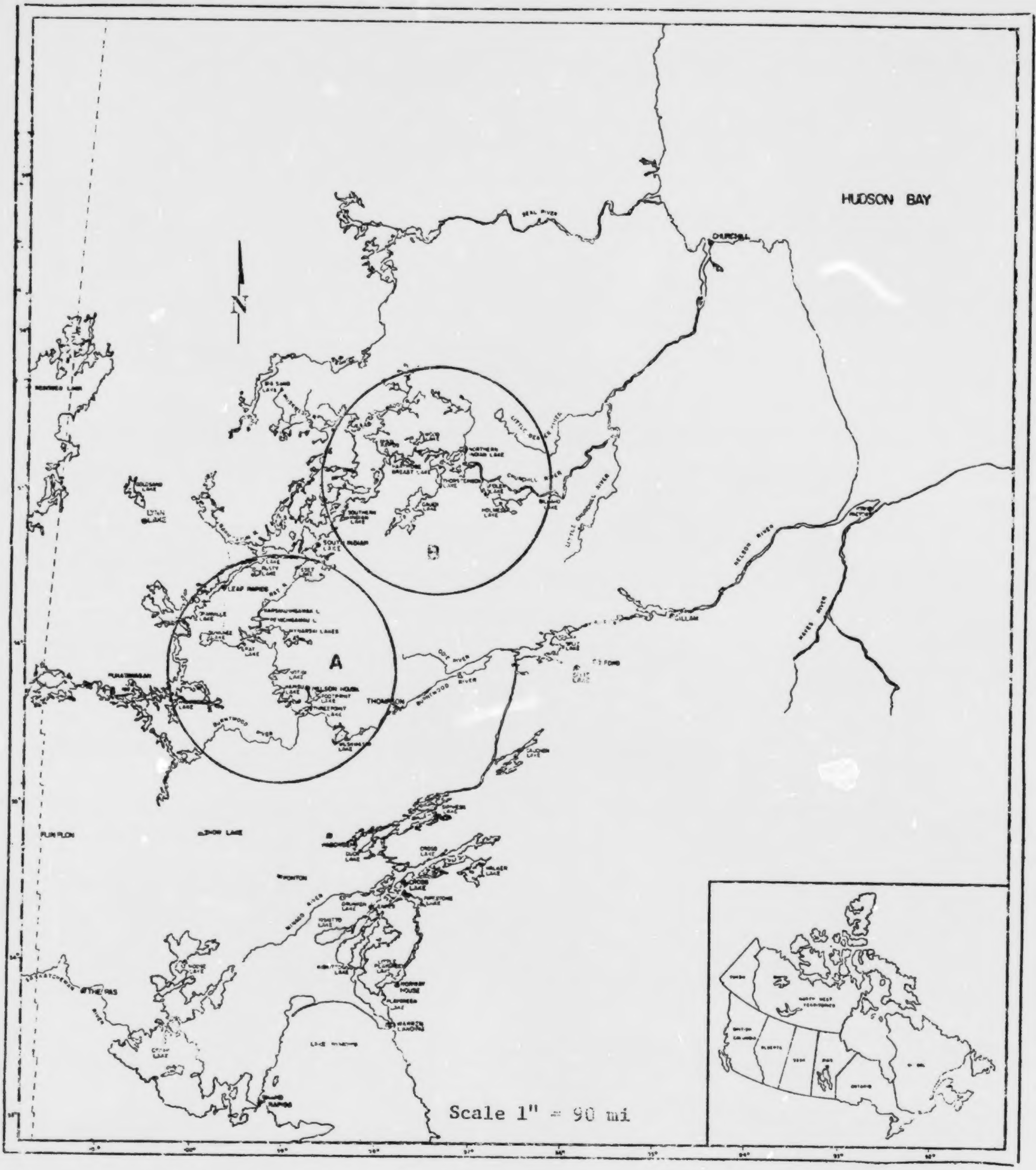

HUDSON BAY
CHURCHILL
SEAL RIVER
N
A
B
LEAF RAPIDS
SOUTH INDIAN LAKE
NORTHERN INDIAN LAKE
SOUTHERN INDIAN LAKE
CHURCHILL RIVER
LITTLE BEAVER RIVER
LITTLE CHURCHILL RIVER
NELSON RIVER
HAYES RIVER
GILLAM
THOMPSON
NELSON HOUSE
FOOTPRINT LAKE
THREEPOINT LAKE
BURNTWOOD RIVER
ODEI RIVER
SPLIT LAKE
LYNN LAKE
FLIN FLON
WEKUSKO LAKE
CROSS LAKE
NORWAY HOUSE
LAKE WINNIPEG
GRAND RAPIDS
Scale 1" = 90 mi

Figure 1. Map of northern Manitoba indicating study areas.

exchange times it was possible to predict the impact of the future diversion.

METHODS

The lower Churchill lakes selected for this study ranged from 23 to 144.7 km^2 in area and from 19 m to 58 m in maximum depth (Table 1, Fig. 1). The Rat-Burntwood lakes ranged from 6.3 to 85.3 km^2 in area and from 8.5 to 12.5 m in maximum depth. These two groups differed significantly in the water exchange times. In the lower Churchill Riv lakes these varied from 1.3 to 9 days while in the Rat-Burntwood syste they were from 30 to 136 days.

Plankton samples were obtained by a series of vertical hauls fro near the lake bottom to the surface using the larger Wisconsin net wit the mouth diameter of 25 cm and mesh size about 77μ. Crustacean abunda was expressed as the number of specimens per cm^2 of lake area or per 1 liter of water, based on the assumption that the filtration efficiency of the net was 100%. The data presented should not be interpreted as true densities but rather as relative abundance values, proportional t the densities, since the nets' true efficiency probably varied between 40-50% (Rawson 1956). The lakes were sampled at one station nearest to the center of the lake and/or to the maximum depth. The samples were taken in most of the lakes from June to September 1973 at one mont intervals.

The results were compared to those of Southern Indian Lake, and Lake Winnipeg.

Table 1. Morphometric characteristics of the lakes of Lower Churchill River system and of Rat-Burntwood River system (from Brown, 1974).

Lake	Water Area km^2	Max. Depth m	Mean Depth m	Water Exchange Day
(Lower Churchill) System				
Missi Rapids		>30		<1
Partridge Breast	23.8	22.5	6.3	1.7
Northern Indian Lake	144.7	58.0	5.7	9.0
Fidler	38.8	19.0	3.0	1.3
Wood	22.9	32.0	9.0	862
Rat-Burntwood System				
Karsakuwigamak	18.8	11.5	2.0	37
Pemichigamau	19.3	5.0	2.2	39
West Mynarski	6.2	8.5	1.7	60
Rat	78.4	14.5	3.7	136
Notigi	15.1	12.5	5.3	30
Wapisu	38.9	10.0	3.3	42
Wuskwatim	45.4	12.0	6.2	37

Table 2. The percentage composition of the crustacean plankton in the lakes of the lower Churchill and Rat-Burntwood River systems in June 1973.

Lake and Date Species	Karsakawigamak 14 June, 1973	Pemichigamau 14 June, 1973	W. Mynarski 14 June, 1973	Rat 14 June, 1973	Notigi 14 June, 1973	Wuskwatim 14 June, 1973	Missi Rapids 13 June, 1973	Partridge Breast 13 June, 1973	Northern Indian 13 June, 1973	Fidler 13 June, 1973	Wood 13 June, 1973
Limnocalanus macrurus Sars				2.5	0.1	0.1	0.6	7.0	0.6	0.3	21.0
Epischura lacustris Forbes	1.2	1.7	0.1	2.5	1.3	8.3					
Epischura nevadensis Lilljeborg						0.1					
Epischura sp. (copepodids)									1.9	1.3	
Diaptomus sicilis Forbes			0.8	0.2	0.6						44.7
Diaptomus oregonensis Lilljeborg	3.0	5.0	2.3	2.5		7.0					
Diaptomus ashlandi Marsh		1.3	0.2	39.1	14.4	11.8	34.8				
Diaptomus wilsonae Reed		0.1		0.1							
Diaptomus sp. (copepodids)								6.3	5.2	7.4	
Diaptomus sp. (nauplii)								21.8	41.3	20.0	
Cyclops bicuspidatus thomasi Forbes	71.9	60.8	31.2	31.9	52.2	41.0	47.8	19.0	24.1	53.0	19.4
Cyclops vernalis Fischer	15.4	14.5	17.8	12.8	13.4	28.3	13.5	43.0	26.4	16.5	14.2
Cyclops scutifer Sars							1.7				
Mesocyclops edax (Forbes)		2.5	1.9	2.0	0.3						
Daphnia retrocurva Forbes	4.3	8.0		1.9	1.2	0.1					
Daphnia galeata mendotae											

	Karsakawigamak 14 June, 1973	Pemichigamau 14 June, 1973	W. Mynarski 14 June, 1973	Rat 14 June, 1973	Notigi 14 June, 1973	Wuskwatim 14 June, 1973	Missi Rapids 13 June, 1973	Partridge Breast 13 June, 1973	Northern Indian 13 June, 1973	Fidler 13 June, 1973	Wood 13 June, 1973
Bosmina longirostris (Müller)	2.3	0.8	0.5	2.4	0.8					1.3	0.6
Chydorus sphaericus (Müller)	0.5		0.5	0.5	0.4			2.8			
Holopedium gibberum Zaddach	0.1	0.2	5.7	0.8	0.4	0.1			0.2	0.3	
Leptodora kindtii (Focke)	0.1			0.4		0.1			0.1		
Polyphemus pediculus (Linné)									0.1		
Total percent	100	100	100	100	100	100	100	100	100	100	100
Total indiv/l	3.4	10.5	70.9	5.4	6.1	7.0	0.6	0.6	1.2	1.2	4.4
No. of species	10	13	11	15	13	13	6	4	8	6	5

RESULTS

During the four months of investigation in the 11 lakes, species of crustaceans were found (17 copepods and 16 cladoce In Tables 2-5 data are presented in such a way as to make poss a comparison of species composition of all lakes under study.

In June (Table 2), all the lower Churchill lakes were ver in plankton (0.6-1.2 ind/l). The dominant species in all *Cyclops bicuspidatus thomasi* and *Cyclops vernalis*. *Limnocal macrurus* was also present in all of them although in very low In addition, single specimens of cladocerans *Daphnia longiremis Chydorus sphaericus*, *Holopedium gibberum* and *Leptodora kindtii* found in some of the lakes. Wood Lake which is situated north Lower Churchill River and does not belong to the riverine lake differed from the remaining lakes showing a much higher percen *Limnocalanus macrurus* and also *Diaptomus sicilis* which was abs most of the riverine lakes.

The lakes of the Rat-Burntwood system had shown, in the several times higher abundances than those on the Lower Churchi amounting from 3.4 to 70.9 ind/l. Although the dominant speci the same - *Cyclops bicuspidatus thomasi* and *Cyclops vernalis*, remaining species present, in particular *Diaptomus ashlandi*, *D oregonensis* and *Epischura lacustris* were found only in these d route lakes. Also, the cladocerans *Daphnia retrocurva*, *Daphni galeata mendotae* and *Daphnia longiremis* were much more abundan

Table 3. The percentage composition of the crustacean plankton in the lakes of the lower Churchill and Rat-Burntwood River systems in July, 1973.

Lakes and Dates Species	West Mynarski 18 July, 1973	Rat 18 July, 1973	Notigi 18 July, 1973	Wapisu 18 July, 1973	Wuskwatim 18 July, 1973	Missi Rapids 16 July, 1973	Northern Indian 16 July, 1973	Fidler 16 July, 1973	Wood 16 July, 1973
Limnocalanus macrurus Sars			0.12					0.16	0.08
Epischura lacustris Forbes	0.6	0.07	0.6	1.7	4.7	1.5			
Epischura nevadensis Lilljeb.						0.6			
Diaptomus sicilis Forbes		0.8	0.1			0.4			41.5
Diaptomus oregonensis Lilljeb.	17.8	2.3	5.2	1.6	7.4	1.3			
Diaptomus minutus Lilljeb.						2.6			
Diaptomus ashlandi Marsh		19.3	10.4	37.8	23.1	12.0	15.3	8.9	
Cyclops bicuspidatus thom. Forbes	15.7	33.6	20.8	11.7	24.3	55.0	59.3	74.3	44.4
Cyclops vernalis Fischer	40.9	11.5	7.0	15.1	22.1	5.0	19.6	6.9	9.4
Mesocyclops edax (Forbes)	4.5	19.5	16.7	8.4	1.9				
Tropocyclops prasinus mex. Kieffer	0.8		2.8						
Daphnia retrocurva Forbes		1.2	27.4	15.1	8.4	1.4			0.5
Daphnia galeata mendotae Birge									

Daphnia longiremis Sars	15.3	3.6	1.6	0.4		2.8		1.5	
Diaphanosoma leuchtenbergianum Fischer		0.6	3.2	3.8	4.2		0.1		

	West Mynarski 18 July, 1973	Rat 18 July, 1973	Notigi 18 July, 1973	Wapisu 18 July, 1973	Wuskwatim 18 July, 1973	Missi Rapids 16 July, 1973	Northern Indian 16 July, 1973	Fidler 16 July, 1973	Wood 16 July, 1973
Bosmina longirostris (O.F. Müller)	0.5					13.8	5.0	5.8	4.1
Chydorus sphaericus (O.F. Müller)	3.5	0.6	1.2	0.4	1.0	0.9			
Holopedium gibberum Zaddach	0.5				0.5	1.9	0.8	0.7	0.03
Leptodora kindtii (Focke)		0.03	0.4	0.03	0.04			0.5	
Eurycercus lamellatus (O.F. Müller)						0.5			
Total percent	100	100	100	100	100	100	100	100	100
Total indiv/l	20.9	70.8	20.5	97.5	22.0	9.0	1.9	3.2	12.4
No. of species	10	13	15	12	12	16	6	9	7

Table 4. The percentage composition of the crustacean plankton in the lakes of the lower Churchill and Rat-Burntwood river systems in August 1973, in Southern Indian Lake in August 1972 and in Lake Winnipeg in July 1969.

Lakes and Dates	Karsakawigamak 20 Aug., 1973	W. Mynarski 20 Aug., 1973	Rat 20 Aug., 1973	Notigi 20 Aug., 1973	Wapisu 20 Aug, 1973	Wuskwatim 20 Aug., 1973	Missi Rapids 21 Aug., 1973	Northern Indian 21 Aug., 1973	Fidler 21 Aug., 1973	Wood 21 Aug., 1973	Southern Indian Aug., 1972	Winnipeg 27 July, 1969.
Species												
Senecella calanoides Juday											0.001	
Limnocalanus macrurus Sars					0.01						0.05	0.03
Epischura lacustris Forbes	0.7	0.4	0.02	0.4	0.04	0.4	0.04			0.01	1.2	1.4
Epischura nevadensis Lilljeb.											0.7	2.7
Epischura sp. (copepodits)								0.2				
Diatomus siciloides Lilljeb.							0.9				3.4	0.2
Diaptomus sicilis Forbes			1.7							6.6	0.7	
Diaptomus oregonensis Lilljeb.	27.7	24.3	17.0	16.5	4.1	20.0	1.7		16.2		4.7	3.5
Diaptomus minutus Lilljeb.							1.7	7.1			3.1	
Diaptomus ashlandi Marsh			5.1	9.9	18.5	9.4	22.1				19.8	40.3
Cyclops bicuspidatus thom. Forbes	4.3	1.1	0.9	6.0	7.3	2.6	36.2	24.7	34.4	58.5	37.3	28.1
Cyclops vernalis Fischer	40.5	20.7	19.9	19.0	12.8	58.7	8.2	47.0	33.1	7.6	8.7	11.5
Mesocyclops edax (Forbes)	0.9	2.2	8.2	20.0	26.5						0.3	
Tropocyclops prasinus mex. Kieffer		22.8		7.0	0.9						0.001	
Eucyclops agilis (Koch)											0.001	
Macrocyclops albidus (Jurine)											0.001	
Daphnia retrocurva Forbes	2.7		0.7	8.4	5.8	4.7	3.0	0.04			3.2	4.9
Daphnia galeata mendotae Birge	0.1	0.1	1.6		20.1	1.7	1.5	0.6	0.9	0.1	1.1	0.9

	Karsakawigamak 20 Aug., 1973	W. Mynarski 20 Aug., 1973	Rat 20 Aug., 1973	Notigi 20 Aug., 1973	Napisu 20 Aug., 1973	Kuskwatim 20 Aug., 1973	Missi Rapids 21 Aug., 1973	Northern Indian 21 Aug., 1973	Fidler 21 Aug., 1973	Wood 21 Aug, 1973	Southern Indian Aug., 1972	Winnipeg 27 July, 1969.
Daphnia longiremis Sars	0.7	0.4	0.3				8.6	0.04			2.4	0.8
Daphnia pulex Leydig											0.001	
Diaphanosoma leuchtenbergianum Fischer	20.9	7.3		6.6	2.6	1.7		0.2			0.6	1.5
Bosmina longirostris (O.F.Müller)	1.3	1.8						15.8	3.8	27.2	3.7	3.6
Chydorus sphaericus (O.F.Müller)		18.8	34.8	6.2	1.5	0.9	14.7	2.4	11.5		8.9	0.4
Holopedium gibberum Zaddach		0.04	9.8				1.5	0.1		0.02	0.2	
Leptodora kindtii (Focke)	0.07		0.02	0.1		0.02		0.2	0.2		0.05	0.1
Ceriodaphnia quadrangula (O.F.Müller)		0.04						1.2			0.001	
Ceriodaphnia pulchella Sars	0.02											
Sida crystallina (O.F.Müller)	0.2										0.07	
Simocephalus serrulatus (O.F.Müller)											0.001	
Eurycercus lamellatus (O.F.Müller)											0.001	
Alona sp.								0.2			0.001	
Graptoleberis testudinaria (Fischer)											0.001	
Total percent	100	100	100	100	100	100	100	100	100	100	100	100
Total indiv./1	39.9	26.5	131.2	33.9	169.7	121.2	8.2	0.9	0.4	19.2	76.4	
No. of Species	13	13	13	11	12	10	12	13	7	7	30(24)	15

Presence of Leptodora kindtii and Diaphanosoma leuchtenbergianum in these lakes as early as June indicates that the lakes warm up quickly and develop planktonic communities typical for moderately rich, temperate lakes. The total number of species was 10-15, much higher than the 4-8 species found in the lower Churchill lakes.

In July (Table 3), the numbers of plankters in the lower Churchill lakes increased slightly (1.8-8.9 ind/1) the highest number being below Missi Rapids, the closest station to the Southern Indian Lake outflow. In addition to species found in June, Diaptomus ashlandi appeared in Northern Indian and Fidler Lakes, and as well, a few more cladocerans were found, particularly Bosmina longirostris. Wood Lake had basically the same species composition as in June with the total abundance increased threefold to 12.4 ind/1. Although the abundance of crustaceans in the lakes of the Rat-Burntwood system increased 3-4 times (21-97 ind/1) the species composition remained unchanged. The same Cyclops bicuspidatus thomasi and Cyclops vernalis were dominant species with Diaptomus ashlandi growing in number. Daphnia retrocurva, Daphnia galeata mendotae and Diaphanosoma leuchtenbergianum were much more abundant than during the month before. The total number of species, from 10-15, was similar to June, while the numbers of species in the lower Churchill lakes were about half as low, from 6-9.

In August (Table 4), the lower Churchill lakes showed even lower abundances of crustacean plankton than in the previous month. 0.4, 0.9 and 8.2 ind/1 were found in Lakes Fidler and Northern Indian, and below Missi Rapids respectively. The species composition did not change significantly but a slightly higher proportion of cladocerans Bosmina

Table 5. The percentage composition of the crustacean plankton in the lakes of the lower Churchill and Rat-Burntwood river systems in September 1973 and in Lake Winnipeg, September 1969.

Lakes and Dates Species	Karsakawigamak 24 Sept., 1973	W. Mynarski 24 Sept., 1973	Rat 24 Sept., 1973	Notigi 24 Sept., 1973	Wapisu 24 Sept., 1973	Missi Rapids 25 Sept., 1973	Northern Indian 25 Sept., 1973	Fidler 25 Sept., 1973	Wood 25 Sept., 1973	Winnipeg 17 Sept., 1969
Limnocalanus macrurus Sars						0.05			0.5	0.02
Epischura lacustris Forbes		0.02		0.5						0.5
Diaptomus siciloides Lilljeb.						7.5				7.7
Diaptomus sicilis Forbes			0.1				6.2			
Diaptomus oregonensis Lilljeb.	22.6	4.6	20.0	11.8	12.3	2.5				3.8
Diaptomus minutus Lilljeb.							6.2			
Diaptomus ashlandi Marsh			3.3	0.7	18.5	14.6		19.2	2.9	35.5
Cyclops bicuspidatus thom. Forbes	24.7	1.2	20.2	6.3	9.3	6.2	21.3	31.0	63.4	11.7
Cyclops vernalis Fischer	37.0	3.6	4.3	16.2	41.1	15.2	21.3	31.0	23.2	29.9
Mesocyclops edax Forbes		2.4	1.1		2.7					
Tropocyclops prasinus mex. Kieffer		12.2	1.1	2.5	5.3					
Daphnia retrocurva Forbes	4.1			2.7	2.8					1.2
Daphnia galeata mendotae Birge		0.1	2.7	0.5	2.8	0.7				3.9
Daphnia longiremis Sars	6.2		0.07			2.7		0.4	0.1	0.2
Diaphanosoma leuchtenbergianum Fischer	1.4		0.07	0.5	0.3	0.1	0.2			1.6
Bosmina longirostris (O.F.Muller)	4.1	4.5	3.2			4.0	6.1		9.4	1.2
Chydorus sphaericus (O.F.Muller)		7.9	44.1	58.1	5.0	46.6	38.8	10.0	0.5	2.3

	Karsakawigamak 24 Sept., 1973	W. Mynarski 24 Sept., 1973	Rat 24 Sept., 1973	Notigi 24 Sept, 1973	Wapisu 24 Sept., 1973	Missi Rapids 25 Sept., 1973	Northern Indian 25 Sept., 1973	Fidler 25 Sept., 1973	Wood 25 Sept. 1973	Winnipeg 17 Sept., 1969
Holopedium gibberum Zaddach								8.4		
Leptodora kindtii (Focke)				0.1	0.07					0.03
Ceriodaphnia quadrangula (O.F.Muller)		0.4								0.2
Sida crystallina (O.F.Muller)									0.01	
Total percent	100	100	100	100	100	100	100	100	100	100
Total indiv/l	1.3	57.9	40.2	15.2	45.1	6.9	0.8	1.4	10.4	63.5
No. of species	7	10	12	11	11	11	7	6	8	16

longirostris and *Chydorus sphaericus* were observed. Also, *Limnocalanus macrurus*, present in June and July, was absent in August samples. A very stable plankton composition throughout the summer was found in Wood Lake with *Cyclops bicuspidatus thomasi*, *Cyclops vernalis*, *Diaptomus sicilis* and *Bosmina longirostris* the most abundant components; however, the total abundance increased in August to 19.2 ind/l.

Most of the Rat-Burntwood lakes reached the maximum abundance of crustaceans in August ranging from 26.5 to 170 ind/l. The numbers of species remained within the same range (from 10-13 species), but some changes in the proportions of particular species occurred. *C. bicuspidat thomasi* decreased in numbers and, in its place, *Mesocyclops edax* and *Tropocyclops prasinus mexicanus* increased in abundance. Among cladoceran *Chydorus sphaericus* was found in very high numbers particularly in Rat and Mynarski Lakes. In September (Table 5) a decrease in the abundanc of plankton was observed both in lower Churchill lakes (0.8-6.9 ind/l) and in Rat-Burntwood Lakes (1.3-57.8 ind/l), but no basic changes in species composition were noticed.

DISCUSSION

There is a very high similarity between the planktonic crustaceans of these two river systems. Out of the twenty-one species found in both groups of lakes as many as 15 species were common to both systems (70%). In both groups of lakes the same dominant species were present: *Cyclops bicuspidatus thomasi*, *Cyclops vernalis*, *Diaptomus ashlandi*, *Diaptomus oregonensis*, *Bosmina longirostris* and *Chydorus sphaericus*. Also, the comparison of the plankton composition of these two groups of lakes with the midsummer plankton composition of Southern Indian Lake and Lake Winnipeg shows a very high degree of similarity (Table 4, 5). All the dominant species of Southern Indian Lake were also dominant in most of the Rat-Burntwood Lakes. Out of the total number of 30 species found in Southern Indian Lake (or 23 after elimination of all littoral species) as many as 20 were encountered in the Rat-Burntwood system. Taking into account that the intensity of sampling was much higher in Southern Indian Lake 87% of common species indicates a very high faunistic similarity. Also, the average abundance of plankters in the Rat-Burntwood Lake was very similar to that of the Southern Indian Lake (87 and 76 ind/l respectively). Although the abundance of the Missi Rapids (or Partridge Breast) plankton was 10 times smaller than that of Southern Indian Lake, the percentage composition, in particular all dominant species, was very similar. Even in the lower lakes, Northern Indian and Fidler with their abundances about 100 times smaller, as much as 65% of the species were common with those of Southern Indian Lake, and 60%

Table 6. The abundance of planktonic crustaceans in the lower Churchill lakes and in the Rat-Burntwood system lakes in various months of 1973 (in numbers of individuals per liter).

Lake	June	July	August	Sept	Average	Water Exchange Time (days)
Lower Churchill system						
Missi Rapids	0.6	8.9	8.2	6.9	6.1	1.0
Partridge Breast	0.6					1.7
Northern Indian	1.2	1.8	0.8	0.8	1.2	9.0
Fidler	1.2	3.2	0.4	1.4	1.5	1.3
Rat-Burntwood system						
Karsakuwigamak	3.4	(21.6)	39.9	1.27	16.5	37
Pemichigamau	10.5					39
West Mynarski	70.9	20.9	26.5	59.9	44.6	60
Rat	5.4	70.8	131.2	40.2	61.9	136
Notigi	6.1	20.5	33.9	15.2	18.9	30
Wapisu	(17.2)	97.5	169.6	45.1	82.3	42
Wuskwatim	7.0	22.0	121.2	(32.3)	45.6	37
Wood	4.4	12.4	19.2	10.4	11.6	862

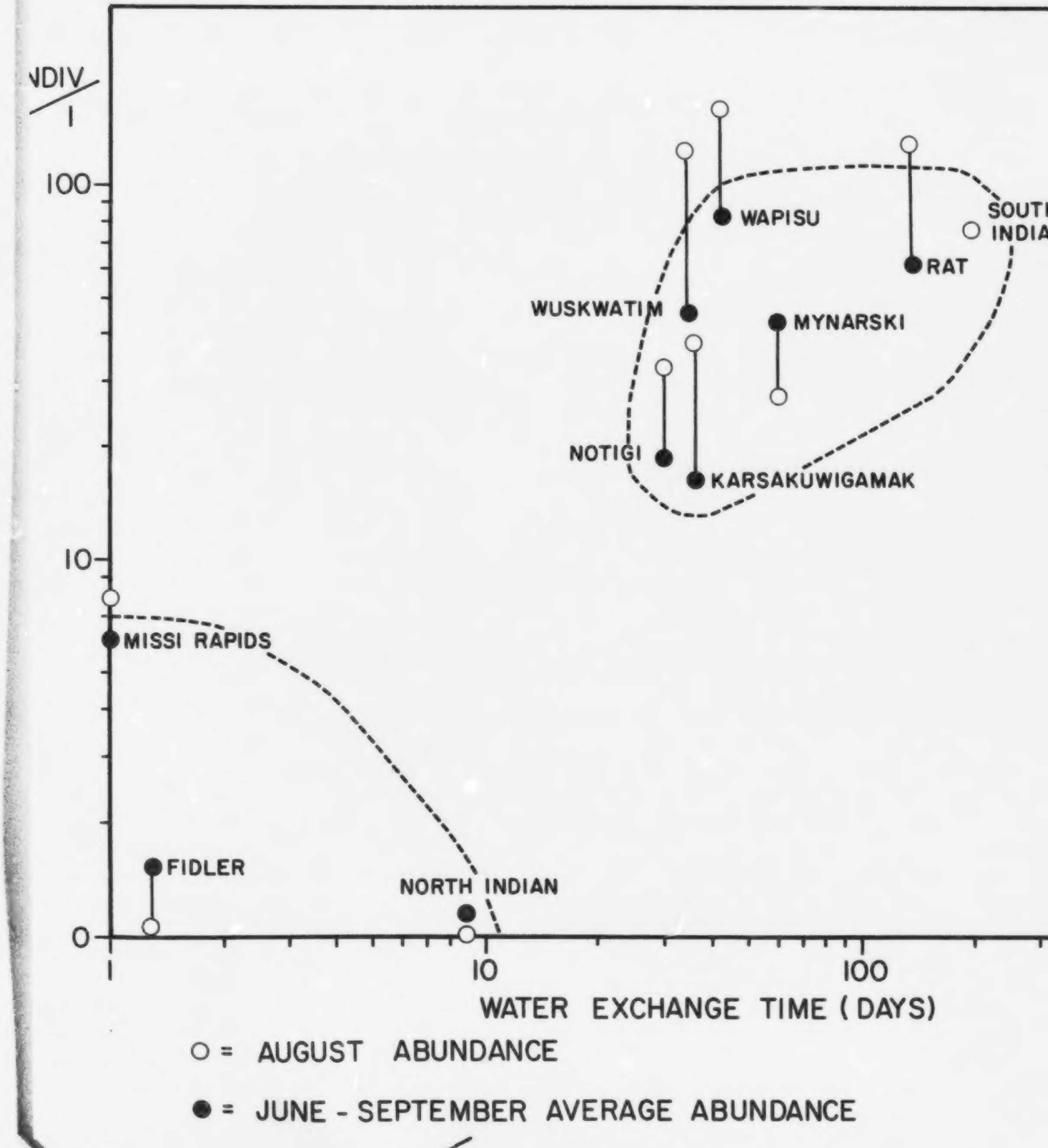
were common with those of Lake Winnipeg. This would indicate that the whole area under investigation represents a rather uniform faunistic region, and that the most significant differences lay not as much in the species composition as in the very low (up to two orders of magnitu lower) quantities in the lower Churchill group of lakes. An explanatio for this paucity of plankton is provided in Fig. 2 and Table 6 where th numbers of planters were correlated with the water exchange time of the lakes considered. Three groups of lakes can be distinguished with widel different water exchange times. The lower Churchill lakes: Northern Indian, Fidler and Partridge Breast all have an extremely short exchang time ranging from less than 1 to 9 days and also the lowest plankton abundance ranging from 1 to 6 ind/l.

The second group: Karsakuwigamak, West Mynarski, Rat, Notigi, Wapisu, Wuskwatim and Southern Indian Lakes have water exchange times ranging from 30-200 days and an average plankton abundance within the range of 16-82 ind/l.

The third group is represented only by one, Wood Lake, with a water exchange time of 862 days and the average plankton abundance of 12 ind/l. Although the number of observations is too small to compute a regression describing the relationship between these two parameters, one can safely say that the very short water exchange time of the first group of lakes (1-9 days) is certainly a limiting factor in developing a rich zooplankton population. The second group of lakes lies within the range in which the plankton abundance increases with the increasing water exchange time. Wood Lake's lower plankton abundance seems to indicate that within the existing chemical conditionscharacteristic for this Shield region, 860 days (about 2 1/2 years) for water exchange is

Fig. 2

The Relation Between The Abundance Of Planktonic Crustaceans And The W Exchange Time.



too long a time to create an optimum condition for plankton develo
Within a uniform geological and climatic region, the nutrient load
proportional to the volume of water entering the lake, i.e. invers
proportional to the water exchange time. Thus Partridge Breast,
Northern Indian and Fidler Lakes have the highest nutrient input a
Wood Lake the lowest. However, there is a minimum water residence
(= exchange time) necessary to create favourable conditions for pl
crustaceans to develop in high numbers. With summer water tempera
15-20°C characteristic for this region, a period varying between 2
weeks is required for completion of the life cycle of the plankton
lakes with water exchange times below these limits do not provide
ditions for the accumulation of produced animals, which are carrie
into the river section where fast currents do not favour the devel
of planktonic populations. This is the basic difference between th
planktonic and benthic populations. The latter benefit from flowi
water as they are attached to the substrate and are able to utilize
drifted food particles, and to produce and accumulate in stream co
a high biomass.

The predicted impact of the diversion on the zooplankton:

The lower Churchill lakes after the diversion will have the f
reduced from the present 30,000 cfs to about 5,000 cfs, i.e. about
times. Such a reduced flow will result in significant reductions o
lake areas and volumes, but finally in the end the water exchange
times will remain similar to the present ones. In such a situation
improvement can be expected per unit of volume after the diversion;
rather an even further decrease in zooplanktonic abundance may resul

due to the reduced water transparency in the lower Churchill la In addition, the reduced areas of lakes with similar plankton d will reduce the total productive capacity proportionally to the reduction of lake volumes.

In the Rat-Burntwood Lakes the diversion will create cond similar to those which exist at present in the lower Churchill i.e. the water exchange time will significantly decrease as com with the present one. The highly similar planktonic community in previous sections) will probably respond in a similar manner a significant decrease in plankton abundance of at least ten ti should be expected. The increasing volume of these lakes due t higher flow after diversion, may in part compensate for the dec water exchange time and maintain it at a possibly higher level present exchange time of the lower Churchill lakes.

RECOMMENDATIONS

The planktonic crustaceans constitute the major food resou the juvenile stages of most fish species. To maintain the zoopl production at the present level is therefore an important condit keep the fish production at the present level. As demonstrated previous section, one has to expect a further diminishing of the already very low abundance of zooplankton in the lower Churchill and a significant decrease in the Rat-Burntwood Lakes which are, present rich in plankton.

By constructing dams, maintaining the present volumes of t lower Churchill lakes, and cutting the flow as projected from ab 30,000 to 5,000 cfs one can expect that water residence time in lakes would proportionally increase about six times improving pr conditions for zooplankton production. This could significantly compensate the unavoidable plankton losses in the Rat-Burntwood after the diversion.

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CONCLUSIONS

1. There is a high faunistic similarity between the pl
Southern Indian Lake, the lower Churchill lakes and
Burntwood Lakes.
2. The lakes of the Rat-Burntwood system are rich in p
comparable to or even richer than Southern Indian L
as a result of a relatively high nutrient input and
water exchange times.
3. The lakes of the lower Churchill display a very lo
abundance, the result of very short water exchange
create unfavourable conditions for the development
crustaceans.
4. The impact of the diversion will reduce the already
of plankton in the lower Churchill lakes, and will
significantly (up to 10 times) the plankton abundan
Burntwood Lakes due to highly increased flushing ra
5. The construction of dams which would maintain the p
of the lower Churchill lakes could significantly in
present level of plankton abundance and compensate
losses of plankton production in the Rat-Burntwood

APPENDIX 5 - VOL. 2 - H

ZOOBENTHOS SURVEY OF THE LOWER CHURCHILL RIVER AND DIVERSION ROUTE LAKES

ZOOBENTHOS SURVEY
OF THE
LOWER CHURCHILL RIVER AND DIVERSION ROUTE LAKES

by

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Winnipeg, Manitoba
August, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

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SUMMARY

1) The Churchill River has a very positive effect on the production of zoobenthos. Lakes on the Churchill had approximately 4 times as many zoobenthic invertebrates as similar lakes not on the Churchill.

2) Zoobenthos in the Lower Churchill River Lakes was extremely dense, averaging over 12,600 organisms/metre^2 This compares with averages of 3188/metre^2 in 5 lakes directly on the diversion route, 3090/metre^2 in the 3 Mynarski lakes adjacent to the diversion route and 2331/metre^2 in Wood Lake adjacent to the Lower Churchill.

3) Following diversion the total production of benthic invertebrates in the Lower Churchill River Lakes will decrease to less than half the present level. Outlet weirs to maintain present water levels would maintain the production of zoobenthos at or near the present level.

4) Following diversion the total production of benthic invertebrates in the Diversion Route Lakes will increase substantially. Initial turbidity problems will have a negative effect on zoobenthos production, however, as the new system equilibrates the total production of zoobenthos in the Diversion Route Lakes can be expected to increase by a factor of more than 4 times.

INTRODUCTION

The term, zoobenthos, refers to the invertebrates that live in or upon the bottom sediments in aquatic habitats. Characteristically this benthic community plays an important role in the metabolism of an aquatic ecosystem and is of critical importance to bottom-feeding species such as whitefish. In addition the young of yellow walleye and northern pike, two carnivorous species often feed extensively on zoobenthos. The quantity and quality of zoobenthos are also good indicators of the general productivity of a waterbody. Consequently, differences in abundance and composition of the zoobenthos in different parts of a lake can often provide useful information on the regional factors influencing general productivity as well as provide a measure of the capacity of an area to support stocks of bottom-feeding fishes.

The primary objectives of the zoobenthos survey on the lower Churchill River lakes and the Diversion Route lakes were:

1) Determine and compare the abundance and composition of zoobenthos in the Lower Churchill River Lakes and the Diversion Route Lakes .

2) Relate abundance and composition of zoobenthos in the different lakes to regional factors. One particularly important aspect is to assess the impact of the Churchill river on zoobenthos of the lakes through which it flows.

3) Relate abundance and distribution of zoobenthos in these lakes to that of other biological components of the ecosystem.

4) Predict the likely impact of diversion of the Churchill River at South Bay on the abundance and composition of zoobenthos in t Lower Churchill River Lakes and the Diversion Route Lakes.

The assistance of Mr. Tom Cleugh, Mr. Ian Davies and Mr. Tom Kozubski who collected the samples is much appreciated.

METHODS

Collection and identification of material:

The zoobenthos survey on the Lower Churchill River Lakes and the Diversion Route Lakes was conducted between June 9, 1973 and Jun 24, 1973. Three to ten samples were collected in each of the 12 lake using a 15x15x23 cm tall Ekman grab. Three of these lakes (Fidler, Northern Indian and Partridge Breast) are on the Lower Churchill Rive five (Karsakuwigamak, Rat, Notigi, Wapisu and Wuskwatim) lie directly on the diversion route, three (west, central and east Mynarsk Lake) are adjacent to the diversion route and will be variously affect by changing water levels and one lake (Wood Lake) lies adjacent to the Lower Churchill River Lakes and will not be affected by the diversion. Sampling was restricted to the offshore, open water areas to reduce shore effects. Sediments were sieved in the field using a Nitex nylon mesh net (apertures 400μ square) and the sieve residues were preserved in approximately 10% formalin. In the laboratory the samples were rinsed to remove most of the formalin and the invertebrates sorted fro the residue with the aid of a stereomicroscope and then preserved in 70% ethanol. All macrobenthos were identified using a stereomicrosope Smaller organisms such as Copepoda, Cladocera and Ostracods were preserved but not enumerated because they were too small to have been sampled quantitatively.

ABUNDANCE AND DISTRIBUTION OF ZOOBENTHOS

Comparative evaluation of zoobenthos in the study area

The zoobenthos in the Lower Churchill Lakes was extre
averaging over 12,600 organisms/metre^2. This compares with a
of 3188/metre^2 in the 5 lakes directly on the diversion route
metre^2 in the three Mynarski Lakes adjacent to the diversion
2331/metre^2 in Wood Lake, adjacent to the Lower Churchill Ri
(Table 1). The abundance of zoobenthos and Pontoporeia in th
area studied including Southern Indian Lake is illustrated in

The average density of benthic invertebrates in sampl
Southern Indian Lake was 3,429/metre^2 over the entire lake an
4364/metre^2 in regions directly influenced by the Churchill R
The density in Southern Indian Lake is two to ten times highe
that reported by Rawson (1960a) for other large lakes such a
Wollaston and Reindeer located in the same general region. I
also higher than that reported for most of the Churchill lake
Saskatchewan (Rawson 1957; Rawson 1960b, and Koshinsky 1971).
(1971) reported that 15 small lakes in the Canadian Shield nea
had an average of 1,552 benthic organisms/meter^2 with a range
from 104 to 3,556 organisms/meter^2. The lakes sampled in thi
are intermediate in size between the Kenora Lakes and large la
as Southern Indian.

Rawson and Koshinsky used a larger mesh for sieving their samples; however, it seems very unlikely that mesh size alone coul explain the comparatively high values for samples from Southern In Lake and the Lower Churchill River Lakes. Sampling techniques use on the small lakes near Kenora were identical to those used on this study. It should be noted that when other variables are similar la lakes are generally much less productive on a per-unit area basis t small lakes and lakes at high latitudes are usually significantly l productive than lakes in more moderate climates.

It is clear that the zoobenthos of the Lower Churchill Rive Lakes is considerably richer than would ordinarily be expected in l of this size at this latitude. The physical and chemical influence the Churchill River has almost certainly had a very positive effect on the production of zoobenthos in Southern Indian Lake. These res did not come as a surprise since other studies in Saskatchewan (Raws 1960a, Rawson 1960, and Koshinsky 1971) have also demonstrated that zoobenthos in Churchill River lakes is almost always considerably ri than the zoobenthos in nearby Shield lakes.

Table 1. Densities of zoobenthos in the Lower Churchill River Lakes, Diversion Route Lakes and selected adjacent lakes.

	SAMPLES	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	AMPHIPODA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
Partridge Breast	4	14940	89	0	3330	4385	233	766	0	1698	0	25,440
Northern Indian	10	1749	124	0	2669	861	40	124	18	227	9	5,821
Fidler	10	597	62	9	3437	635	178	435	18	284	0	6,629
Average of Lower Churchill Lakes		5795	92	3	3437	1960	150	442	12	736	3	12,630
Wood Lake	10	440	0	0	1621	138	13	89	0	31	0	2,331
East Mynarski	6	2634	0	0	0	200	37	244	15	326	15	3,478
Central Mynarski	4	2065	0	0	0	433	0	1388	0	255	11	4,151
West Mynarski	5	497	0	0	595	329	98	71	35	9	0	1,634
Average of Mynarski Lakes		1732	0	0	201	321	45	568	17	197	9	3,090
Karsakuwigamak	5	1101	98	0	9	248	142	116	9.0	231	0	1,953
Rat	10	1314	62	4	1039	821	93	182	0	93	0	3,610
Notigi	6	1939	59	0	903	600	52	259	0	81	0	3,892
Wapisu	5	2247	124	9	915	506	89	355	0	257	9	4,510
Wuskwatim	3	400	104	0	814	178	133	15	0	15	0	1,658

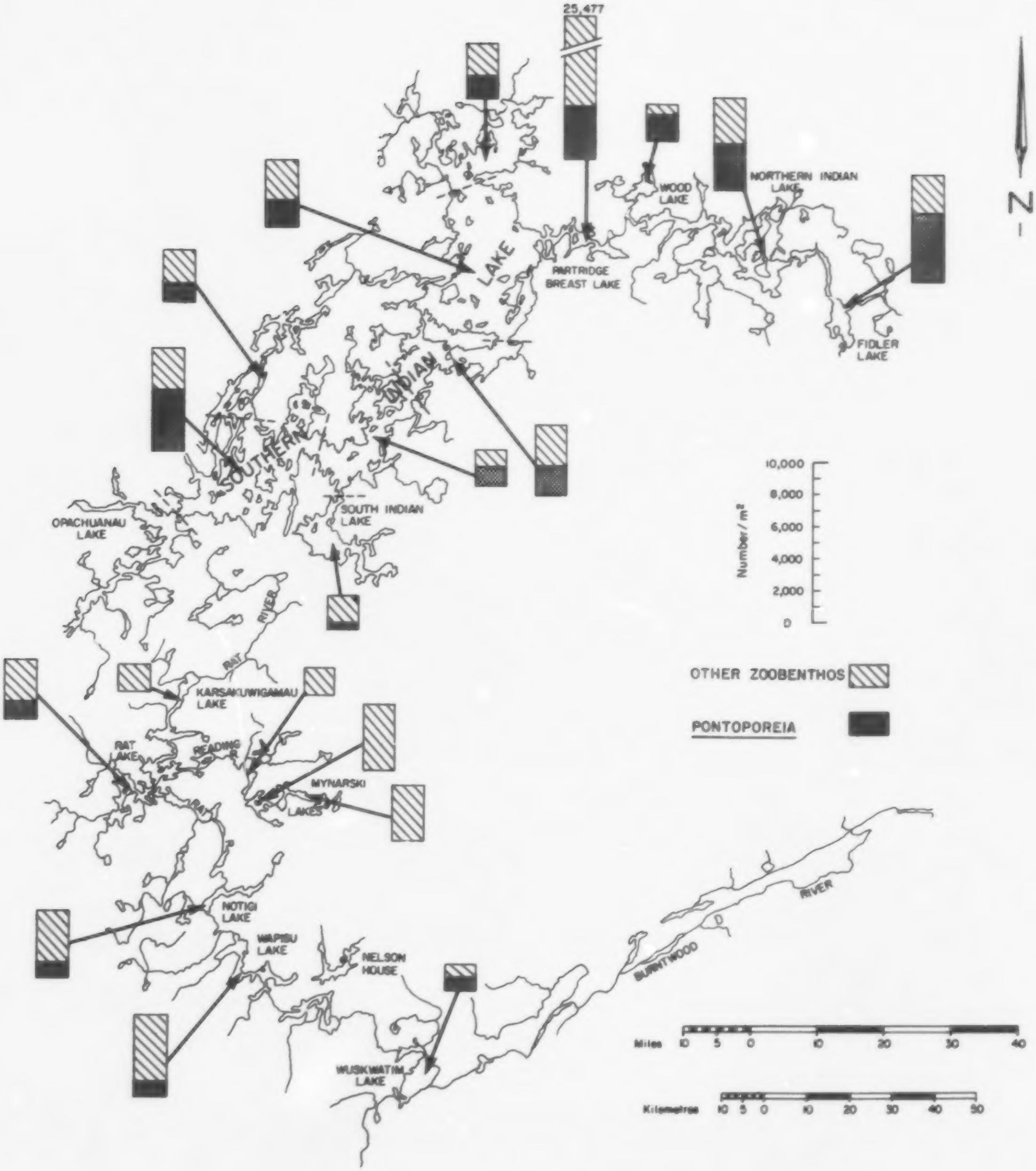
25,477
N
WOOD LAKE
NORTHERN INDIAN LAKE
PARTRIDGE BREAST LAKE
FIDLER LAKE
SOUTHERN INDIAN LAKE
SOUTH INDIAN LAKE
OPACHUANAU LAKE
10,000
8,000
6,000
4,000
2,000
0
Number/m²
RAT RIVER
KARSAKUWIGAMAU LAKE
OTHER ZOOBENTHOS
PONTOPOREIA
RAT LAKE
READING R.
MYNARSKI LAKES
RAT
NOTIGI LAKE
WAPISU LAKE
NELSON HOUSE
BURNTWOOD RIVER
WUSKWATIM LAKE
Miles 10 5 0 10 20 30 40
Kilometres 10 5 0 10 20 30 40 50

Figure 1. Abundance of zoobenthos and Pontoporeia in the Lower Churchill River Lakes, the Diversion Route Lakes and Southern Indian Lake.

Faunal Characteristics

As in Southern Indian Lake the areas influenced by the Churchill River have substantially higher populations of zoobenthos than areas not influenced by the Churchill River. The average densities of zoobenthos in the Lower Churchill River Lakes was 5.4 times as high as in Wood Lake, an adjacent Shield Lake, 4.0 times as high as the average in the Diversion Route Lakes and 4.1 times as high as the average in the Mynarski Lakes.

The freshwater shrimp (Pontoporeia affinis), an important whitefish food, occurred in all lakes sampled, excepting the three Mynarski Lakes. It was very abundant in the Lower Churchill River Lakes (2,669 to 4,311/metre^2) where it represented 14 to 65% of the total and less abundant in the Diversion Route Lakes (9 to 1039/metre^2) where it represented 0.5 to 49% of the total. As indicated no Pontoporeia were collected in the Mynarski Lakes and in Wood Lake the 1621 Pontoporeia/metre^2 represented 70% of the total.

Midges (=Diptera), in particular Chironomid larvae and pupae, were relatively abundant in all lakes and frequently accounted for more than 50% of the total organisms. On average they were several times more abundant in the Lower Churchill River Lake than in any of the other lakes.

Finger nail clams (Sphaeriidae) were generally the third most abundant group and on the average made up 6-16 percent of the total fauna in the four groups of lakes. As with Pontoporeia and Diptera the

Sphaeriidae were on the average several times more abundant in Lower Churchill Lakes than in other lake groupings.

Oligochaete worms were usually the third most abundant group of organisms. Unlike the previous three groups the average density was greatest in the Mynarski Lakes.

There is considerable variation between samples - even from samples within the same region. This is typical of benthos surveys and is related to numerous variables including depth, substrate type, dredge effectiveness and sorting efficiency. Estimated densities are undoubtedly low since no sampler is 100% effective under all conditions.

Relationship to other biological parameters:

Each of the biological communities that were studied provide useful information on the productivity of the system.

Phytoplankton have a very short life cycle that can be measured in days and these groups can respond very quickly to changes in water quality. Phytoplankton are, however, carried passively by water currents and consequently if a lake is flushed too rapidly lake forms will not have a chance to develop large populations.

Zooplankton crustaceans are also carried more or less passively by water currents; however, they have a life cycle several times longer than phytoplankton and consequently their response time to altered water quality is much slower. In addition most plankton crustaceans are not well adapted to living in rivers and consequently their greatest abundance is frequently associated with the degree of protection from currents rather than with water quality.

The zoobenthos fauna can be regarded as an integrater of annual conditions since most benthic invertebrates have a one-year life cycle and individual organisms remain on or in the lake sediments for most or all their life span. Most benthic invertebrates feed on organic detritus and/or other invertebrates and consequently distribution and abundance in lakes is usually related to biological production in the water column. In the case of a flowing system biological products from upstream areas may form a major proportion of the available food. This is apparently the case in the Lower Churchill River Lakes.

The fish fauna represent an even longer integrater of conditions in a lake since the life cycle for most species is of several years' duration. Fish are also capable of migrating long distances and consequently it is quite likely that an individual fish specimen will have spent different parts of his life in different regions of the lake.

The standing crop of phytoplankton and primary production was not well correlated with the distribution of zoobenthos (Hecky and Harper, 1974). Zooplankton abundance was even less related to the distribution of zoobenthos (Patalas and Salki, 1974). This isn't surprising since the zoobenthos is not carried passively by water currents and is much better able to utilize food materials imported from elsewhere in the system. As expected there was reasonably good correlation between zoobenthos abundance and the catch of fish in the experimental nets (Ayles _et al._, 1974). The catches of whitefish, a bottom feeding species and also the major commercial species, were, as one might expect, usually particularily well correlated with zoobenthos abundance.

IMPLICATIONS OF PROPOSED HYDRO-ELECTRIC DEVELOPMENTS

Rationale and basic assumptions:

Because of the complexity of the Churchill Diversion the usual arguments concerning the impact of hydro-electric reservoirs on biological productivity are not as applicable as one might expect. In a more typical situation when a lake is impounded for hydro-electric purposes the level of the lake is raised but the outlet of the lake remains at the same location and flow patterns are not drastically changed. In addition most hydro-electric reservoirs are subject to very severe winter drawdown. When these situations prevail it is usually safe to predict that 1) input of nutrients from flooded land will produce an initial increase in benthic productivity; 2) winter drawdown patterns will drastically reduce littoral zoobenthos; and 3) benthic production in the reservoir will eventually stabilize at a level somewhat below pre-impoundment levels. It would be unwise to accept such general predictions without first taking the unique features of the Churchill Diversion into account.

The factor considered to be of prime importance in the prediction of benthic productivity following diversion is the over-riding importance of the Churchill River as a positive factor that enhances the production of zoobenthos.

Diversion of the Churchill River at South Bay will reduce the amount of nutrients (fertilizer) and organic products entering the Lower Churchill River Lakes and will eventually reduce zoobenthic production on a unit area basis to approximately two thirds of the present level. When changes in area and seasonal water level fluctuations are taken into account it seems very likely that the total production of benthic invertebrates will be less than half the present level. It is anticipated that the zoobenthos production in these lakes could be maintained at or near present levels if outlet weirs were constructed to maintain present water levels.

Diversion at South Bay does introduce nutrients and organic products to the Diversion Route Lakes and in essence they will become the future Lower Churchill River Lakes. Initial turbidity problems along the diversion route will have a negative effect on the overall productivity in these lakes, however, even during the years of stabilization zoobenthic production in these lakes can be expected to increase over present levels. Eventually the production of zoobenthos in those parts of the Diversion Route Lakes not subject to severe water level fluctuations will likely stabilize at levels approximately equivelent to those presently found in the Lower Churchill River Lakes. This would mean approximately a four fold increase in the densities of zoobenthos as well as in the major groups, freshwater shrimp, midge larvae and finger nail clams. Because of increases in the areas of these lakes the total production of zoobenthos in this part of the study area will likely increase by more than four times.

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APPENDICES

Appendix Table 1. Abundance of benthic invertebrates in Partridge Breast Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	7.5	1-2	1,154	-	-	1066	1110	-	266	-	266	-	3,862
02	7.8	2-6	12,343	-	-	-	1199	-	1288	-	-	-	14,830
03	11.9	-	4,484	44	-	7681	9058	444	888	-	4484	-	27,083
04	4.0	1.3.4	41,780	311	-	4573	6172	488	622	-	2042	-	55,988.0
AVERAGE			14,940.0	89.	-	3330	4385.0	233.	766.	-	1698.		25,440

Appendix Table 2. Abundance of benthic invertebrates in Northern Indian Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	6.8	3-4	133	-	-	-	133	44	89	-	-	-	399
02	26.0	1-2	266	-	-	1288	133	89	-	89	44	89	1,998
03	8.0	1-2	1865	42	-	7282	2131	-	-	-	178	-	11,498
04	8.0	-	666	-	-	5994	844	-	-	-	222	-	7,726
05	16.2	-	4218	-	-	89	799	-	-	-	-	-	5,106
06	2.7	-	2531	177	-	3241	1687	-	799	-	844	-	9,279
07	10.5	-	1687	311	-	4840	488	133	89	44	89	-	7,681
08	12.5	-	1110	311	-	1687	1021	44	133	-	44	-	4,350
09	3.1	-	3730	89	-	1288	266	-	133	44	666	-	6,216
10	6.5	2-3	1288	311	-	977	1110	89	-	-	178	-	3,953

Appendix Table 3. Abundance of benthic invertebrates in Fidler Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules

STATION	SAMPLES	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	1	6.0	1-2	844	44	-	10212	444	-	799	44	400	-	12787
02	1	5.0	1-2	710	-	-	7015	666	-	977	-	710	-	10078
03	1	6.0	1-2	355	-	-	3730	400	-	311	-	133	-	4929
04	1	5.0	1-2	799	-	-	3330	622	-	799	133	488	-	6171
05	1	6.0	1-2	1110	-	-	12920	400	-	888	-	622	-	15940
06	1	11.0	1-2	311	-	-	1732	1288	44	44	-	178	-	3597
07	1	12.0	3	1154	488	44	3552	444	1154	355	-	222	-	7413
08	1	4.0	3	400	44	-	533	488	222	-	-	44	-	1731
09	1	11.0	3-5	800	44	-	89	488	-	133	-	44	-	1598
10	1	11.0	3-5	488	-	44	-	1110	355	44	-	-	-	2041

Appendix Table 4. Abundance of benthic invertebrates in Wood Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROP-TERA	TRICHOPTERA	PONTOPORETA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	8.0	2	266	-	-	2531	222	89	133	-	89	-	3330
02	12.	6	-	-	-	799	-	-	-	-	-	-	799
03	16.	-	266	-	-	1865	178	-	-	-	-	-	2309
04	4	1	44	-	-	266	-	-	44	-	-	-	354
05	14	-	533	-	-	311	89	-	-	-	44	-	977
06	19	-	2309	-	-	133	-	-	178	-	-	-	2620
07	21	6	-	-	-	977	-	-	222	-	89	-	1288
08	16	-	666	-	-	3730	577	-	89	-	-	-	5062
09	16	-	222	-	-	3241	222	44	178	-	-	-	3907
10	16	1	89	-	-	2353	89	-	44	-	89	-	2664
AVERAGE			440	-	-	1621	138	13	89	-	[illegible]	-	[illegible]

Appendix Table 5. Abundance of benthic invertebrates in East Mynarski Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules

EAST MYNARSKI 5-10

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
05	6.5	1	1243	-	-	-	222	-	533	-	1376	-	3374
06	2.6	Grassy	666	-	-	-	266	133	-	44	89	-	1198
C7	3.3	1	10256	-	-	-	266	89	311	44	44	-	11,010
08	10.1	-	1288	-	-	44	44	-	89	-	-	44	1509
09	10.3	-	1199	-	-	-	222	-	444	-	178	-	2043
10	6.9	1	1154	-	-	-	178	-	89	-	266	44	1731
AVERAGE			2634	-	-	7	200	37	244	15.0	326	15.0	3478

Appendix Table 6. Abundance of benthic invertebrates in Central Mynarski Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	5.6	1-6	2886	-	-	-	799	-	1021	-	355	44	5105
02	10.8	1-6	1510	-	-	-	222	-	1510	-	89	-	3331
03	9.9	1-6	1598	-	-	-	266	-	844	-	44	-	2752
04	4.0	1-6	2264	-	-	-	444	-	2176	-	533	-	5417
AVERAGE			2065	-	-	-	433	-	1388	-	255	11.0	4151

Appendix Table 7. Abundance of benthic invertebrates in West Mynarski Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	4.0	1	1332	-	-	-	178	44	266	-	-	-	1820.
02	3.0	1	44	-	-	-	311	222	-	44	-	-	621.0
03	3.5	6	222	-	-	-	577	178	89	-	-	-	1066.
04	1.25	1	444	-	-	2975	444	44	-	133	-	-	4040.
05	7.0	?	444	-	-	-	133	-	-	-	44	-	621.0
AVERAGE			497	-	-	595.	329.	98.	71.0	35.	9.0	-	1634.0

Appendix Table 8. Abundance of benthic invertebrates in Karsakuwigamak Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	2.4	3	1465	133	-	-	222	400	178	-	-	-	2398
02	2.2	1	755	266	-	-	222	89	89	44	178	-	1643
03	4.0	1	977	-	-	44	266	44	89	-	133	-	1553
04	2.4	?	1066	-	-	-	266	44	178	-	444	-	1998
05	2.2	1-2	1243	89	-	-	266	133	44	-	400	-	2175
AVERAGE			1101	98.	-	9.0	248.0	142.	116.	9.0	231.0	-	1953.0

Appendix Table 9. Abundance of benthic invertebrates in Rat Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	2.5	1-5	-	-	-	-	355	89	-	-	-	-	444
02	9.2	1-2	1954	-	-	222	1154	89	222	-	311	-	3952
03	15.2	1-2	2398	-	-	444	1643	-	932	-	222	-	5639
04	3.0	6	355	89	-	622	44	44	-	-	-	-	1154
05	5.2	2	888	89	-	2087	222	-	89	-	89	-	3464
06	9.3	1-2	1199	-	-	266	844	89	133	-	-	-	2531
07	4.9	1-2	488	178	-	3019	311	-	89	-	44	-	4129
08	9.5	1-2	977	-	-	977	1421	577	311	-	-	-	4263
09	5.2	1-2	799	44	-	1199	444	44	-	-	222	-	2752
10	5.0	6	4084	222	44	1554	1776	-	44	-	44	-	7768
AVERAGE			1314.	62.	4.0	1039.	821	93.	182.0	-	93.	-	3610.

Appendix Table 10. Abundance of benthic invertebrates in Notigi Lake. Substrate code. 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	9.0	6	2442	-	-	266	666	44	400	-	266	-	4084
02	4.8	-	488	222	-	2353	311	44	-	-	-	-	3418
03	5.8	1-2	1066	44	-	44	1110	222	89	-	44	-	2619
04	2.5	1-2	1199	89	-	2620	444	-	178	-	-	-	4530
05	11.7	1	4174	-	-	89	400	-	133	-	44	-	4840
06	9.5	1	2264	-	-	44	666	-	755	-	133	-	3862
AVERAGE			1939	59	-	903	600	52	259	-	81.0	-	3892

Appendix Table 11. Abundance of benthic invertebrates in Wapisu Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	5.0	1.2	3286	44	-	2353	577	-	133	-	444	-	6837
02	10.0	1.2	4529	-	-	89	1510	178	1243	-	577	-	8126
03	5.2	1.2	1554	266	-	577	44	44	133	-	222	-	2840
04	4.4	1.2	1288	222	44	1554	355	133	44	-	44	-	3684
05	3.5	1.2	577	89	-	-	44	89	222	-	-	44	1065
AVERAGE			2247	124	9	915	506	89.0	355	-	257	9.0	4510

Appendix Table 12. Abundance of benthic invertebrates in Wuskwatim Lake. Substrate code: 1 brown mud; 2 grey clay; 3 sand; 4 gravel; 5 rock; 6 nodules.

STATION	DEPTH (meters)	SEDIMENT TYPE	DIPTERA	EPHEMEROPTERA	TRICHOPTERA	PONTOPOREIA	SPHAERIIDAE	GASTROPODA	OLIGOCHAETA	HIRUDINEA	NEMATODA	MISCELLANEOUS	TOTAL
01	2.7	1.2	222	89	-	1288	44	400	-	-	44	-	2087
02	5.2	1.2	799	222	-	310	400	-	44	-	-	-	1775
03	6.5	1.2	178	-	-	844	89	-	-	-	-	-	1111
AVERAGE			400	104	-	814.0	178.0	133	15.0	-	15.0	-	1658

APPENDIX 5 - Vol. 2

The Fisheries of the Lower Chur
The Rat-Burntwood Lakes and the
Lakes; Present Conditions
Implications of Hydroelectric D

THE FISHERIES OF THE LOWER CHURCHILL LAKES THE RAT-BURNTWOOD LAKES AND THE UPPER NELSON LAKES:

PRESENT CONDITIONS AND THE IMPLICATIONS OF HYDROELECTRIC DEVELOPMENT

by

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for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

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SUMMARY

Lower Churchill Lakes

1. The fish fauna was fairly typical of Churchill River drainage lakes. Whitefish, pike and suckers dominated numerically, with whitefish and northern pike comprising nearly equal proportions in weight in the catches. Yellow walleye were not prominent in catches, nor were cisco, perch, and lake trout.

2. On the whole, catch per unit efforts compared favourably to those of upstream lakes of the Churchill River. Moreover, yields of the major commercial species (whitefish, pike and walleye) were 1.6 to 2.1 times as great as those in Wood Lake (a Shield lake).

3. Growth of whitefish was slower than upstream areas (Southern Indian), however conditions were comparable. Growth of pike and walleye were better than most upstream lakes of the Churchill River.

4. Food of whitefish was predominantly benthic; chironomid larvae, sphaeriids, mayfly nymphs, valvatids, and trichopterans. Dietary items of pike and walleye were mainly fish prey; whitefish, cisco white and longnose suckers, burbot and sticklebacks.

5. Diversion and flow regulation will seriously affect the majority

of fishes, particularly the commercial species. Diversion will reduce the area of the lakes as much as 76%, reducing the general production of each lake. Exposed lake bottom will release sediments to the lakes creating a problem with turbidity and negatively affecting all trophic levels. Annual flow regulation will create drawdowns of up to 10 feet which will inhibit the establishment of a successful littoral zone. Decreases in water level, to take place during the fall and winter, could inhibit fall spawning species (e.g. whitefish and cisco) and could expose areas of spawn that have been successfully deposited.

Rat-Burntwood

1. Species composition for fish in the Rat-Burntwood lakes was not as varied as was species composition in Southern Indian or Sipiwesk Lake. Walleye was the most abundant commercial species whitefish the least.

2. Whitefish were less prevalent in the Rat-Burntwood lakes than in Southern Indian Lake. Whitefish from the Rat-Burntwood lakes we in similar condition to whitefish from Southern Indian and they had, in general, a greater mean age than the whitefish from Southern Indian Lake.

3. Walleye were plentiful from the Rat-Burntwood lakes, growth appea quite uniform throughout most of the system, and condition was typical for northern latitudes but poorer than the condition of walleye from Southern Indian Lake.

4. Northern pike and cisco were found throughout the Rat-Burntwood system in varying quantities while sauger and yellow perch were relatively scarce.

5. The diversion and control of the Churchill River flow at Notigi will have a marked effect on the fish habitat as it exists presently in the Rat-Burntwood lakes. Overall production will increase as the total water area increases. There will likely be a reduction in whitefish and cisco production, and an increase in northern pike and white sucker production, all on a per-unit-area basis. Goldeye may become established in the new reservoir from Southern Indian Lake. An excellent tailrace fishery at Notigi for walleye could eventually be created.

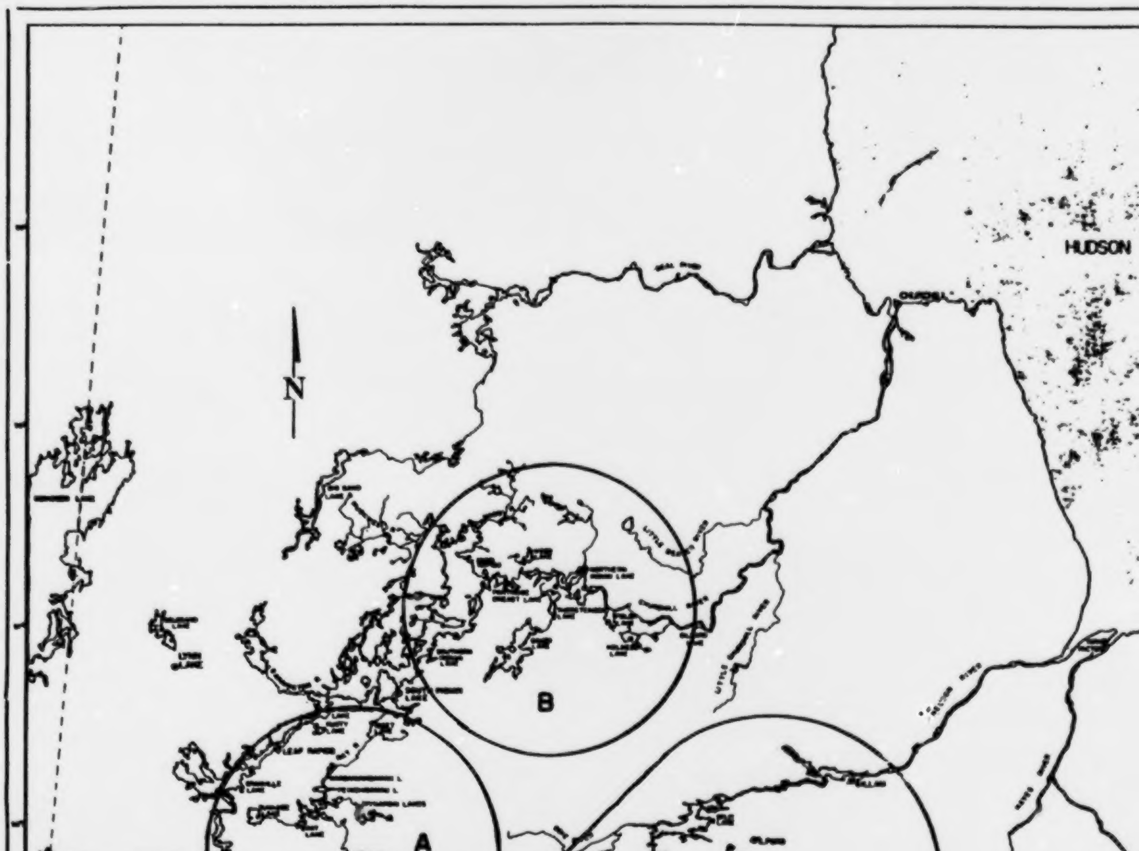
Nelson Lakes

1. Growth rates and condition of the commercially important fish species for the upper Nelson River lakes is generally slightly better than those for fish species from Southern Indian Lake but poorer than those for fish species from the Lake Winnipeg outlet lakes.
2. Cross Lake had a high overall production of commercially important species having twice the production recorded experimentally from Southern Indian Lake. Kettle Reservoir had the poorest production having approximately one-quarter the production recorded from Southern Indian Lake.
3. Moose Lake had a high production of whitefish and cisco. Statistical analysis suggested that these populations from Moose Lake were discrete from whitefish and cisco populations found in the new Kettle Reservoir.
4. Sipiwesk Lake has been a reservoir since the implementation of the Kelsey Hydro Plant in 1960. There has been a noticeable shift in the dominant commercial species from whitefish to pike. Goldeye appear to have increased in population size.
5. Split Lake will receive the initial impact on the Nelson River of the Churchill River diversion. A related increase in silting and turbidity will act as a detriment to the fish species present in Split Lake. There may be problems with debris in the lake and access to the shoreline for local residents. The commercial and domestic fishery will likely suffer.

INTRODUCTION

This study has been a portion of the fisheries-limnology pro of the Lake Winnipeg, Churchill and Nelson Rivers Study. This repo is concerned with the fish populations of the lower Churchill lakes Rat-Burntwood lakes and the Nelson River lakes (Figure 1) how hydro electric development in this region has affected them to date and h the proposed hydroelectric developments may affect them in the futu It is a summary of the data gathered on these river systems during open-water season of 1973. It does not deal with the commercial fi complex of the Churchill or Rat-Burntwood lakes but does touch brie on the existing commercial fishery of the Nelson lakes.

This report has been divided into three sections according t geographic location (Fig. 1A, B, C). Where information is available general ecology of each of the major species is discussed. Where possible, a discussion of the effects of hydroelectric developments a fish species is presented and recommendations to reduce these eff are put forward.


HUDSON
N
A
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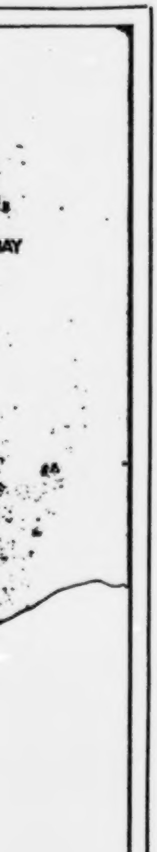
C
Scale 1" = 90 mi

Figure 1. Map of northern Manitoba indicating study areas.



LOWER CHURCHILL LAKES

1.1. INTRODUCTION

The lower Churchill lakes described in this study, are co
to Partridge Breast, Northern Indian, and Fidler Lakes. Wood La
included in the investigations to assess the differences between
that received the Churchill River flow and a lake that received
Precambrian Shield runoff .

The diversion of up to 30,000 cfs of the Churchill River
drastically alter these lower Churchill River lakes. Lake level
drop from 8.4-10.3 feet and areal changes will be as much as 76%
Fidler Lake (Brown, MS 1974). Annual fluctuations will increase
a range of 3.2-4.3 feet up to 7.2-8.7 feet. The lower water lev
expose large areas of old lake bottom some of which will be colo
typical shoreline vegetation. However, a large area will remain
of disequilibrium because of the large fluctuation in water leve
area will extend below mean annual water level and the fluctuati
disrupt the establishment of a viable littoral zone. The lower
levels will expose for erosion by wave action, sediments deposit
to diversion and this eroded material will increase turbidity ov
areas of the lake.

The results of the investigations into the fish of the lo
Churchill River are summarized here. The implications that chan
have on the fish are discussed and recommendations are presented

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1.2. METHODS

The fish populations of the four lakes were studied during summer of 1973. Two sampling trips were made to each lake on the following dates: Fidler (June 3-7 and August 10-12), Wood (June and August 13-16), Partridge Breast (June 17-25 and August 17-20) Northern Indian (June 30-July 18 and August 22-31). The methods fish sampling, data collection and analysis are essentially the s as outlined in Ayles and Koshinsky (MS 1974).

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1.3. SPECIES COMPOSITION

Fish species found in the lower Churchill in 1973 are
in Table 1.1. No new species were recorded from those alread
from the other lakes of the Churchill River drainage (McTavis
Rawson and Atton, 1953; Rawson, 1957b, 1960; Ayles and Koshins
MS 1974).

Table 1.1. Occurrences of fish species in the lower Churchill River lakes and the Churchill River.

	Whitefish (*Coregonus clupeaformis*)	Round whitefish (*Prosopium cylindraceum*)	Walleye (*Stizostedion vitreum*)	Northern pike (*Esox lucius*)	Yellow perch (*Perca fluviatilus*)	Lake trout (*Salvelinus namaycush*)	Brook trout (*Salvelinus fontinalis*)	White sucker (*Catostomus commersoni*)	Longnose sucker (*Catostomus catostomus*)	Shorthead redhorse (*Moxostoma macrolepidotum*)	Cisco (*Coregonus artedii*)	Burbot (*Lota lota*)	Trout-perch (*Percopsis omiscomaycus*)	Lake chub (*Couesius plumbeus*)	Longnose dace (*Rhinichthys cataractae*)	Spottail shiner (*Notropis hudsonius*)	Blacknose shiner (*Notropis heterolepis*)	Ninespine stickleback (*Pungitius pungitius*)	Brook stickleback (*Culaea inconstans*)	Flathead chub (*Platygobio gracilis*)	Emerald shiner (*Notropis atherinoides*)	Slimy sculpin (*Cottus cognatus*)
Partridge Breast	x			x				x	x		x	x	x	x	x		x					
Northern Indian	x		x	x	x	x		x	x		x	x	x					x				x
Fidler	x		x	x		x		x	x		x	x				x		x				
Wood	x		x	x		x		x	x	x	x	x	x	x	x	x		x	x			x
Churchill River^a	x						x	x			x			x			x	x				
Churchill River^b	x	x		x				x	x		x	x	x	x	x	x		x	x	x	x	x

a. 1973 fisheries sampling

b. pers. comm. C.C. Lindsey

1.4. FISH STANDING CROP

In the lower Churchill lakes, whitefish were by far the dominant catch, followed by white suckers and pike. Since catch per unit effort alone cannot be assumed to represent production, mean weights of each fish species were applied to mean numbers of fish caught to yield catch per unit effort in pounds (Table 1.2). The catch per unit effort (C.U.E. lb.) for each fish species varied according to the species, and type of habitat available in the different water bodies. On the whole, the average catches of the commercial species (whitefish, pike and walleye) were much greater for the three lower Churchill River lakes as compared to the Shield lake, Wood. Also, lower Churchill lakes catches were on par with or greater than those reported from other Churchill mainstem lakes (Rawson, 1960; Ayles and Koshinsky, MS 1974).

Following diversion, the lower water areas will result in an overall reduction in fish population. As well as this reduction, there is reason to believe that there will be a decline on a per-unit-area basis, the magnitude of which will vary according to the species involved. The following discussion of the ecology of each species refers to changes to production on a per-unit-area basis. Total change in production from the present will be a combination of these two factors.

Table 1.2. Mean catch per unit effort in pounds and percent composition of fishes [] from a single gang of nets in the lower Churchill River drainage lakes.

Lake	Whitefish	Pike	Walleye	Lake Trout	Cisco	Burbot	Totals
Partridge Breast	77.8(45.3)	83.1(48.4)	0.3(0.2)	-	2.4(1.4)	8.2(4.8)	171.8
Northern Indian	66.9(37.1)	87.5(48.5)	16.8(9.3)	0.7(0.4)	4.4(2.4)	3.0(1.7)	179.3
Fidler	82.9(53.4)	57.7(37.3)	3.6(2.0)	-	3.2(2.2)	7.6(4.9)	155.0
Wood	47.8(30.7)	39.3(25.3)	11.8(7.6)	47.7(30.6)	0.5(0.3)	8.6(5.5)	155.7

1.5. LAKE WHITEFISH

Age, growth, and condition:

From the back-calculated data, the length of whitefish in Wood and Partridge Breast Lakes for a given age is greater than the lengths from Northern Indian or Fidler. It appears that Wood Lake whitefish have an advantage in growth for the first 5 years after which the rate of growth is surpassed by the rate of growth of whitefish from the lower Churchill lakes (Table 1.3). When sampled length-age data were analyzed significant differences among rates of growth of whitefish from the four lakes were apparent. Partridge Breast and Northern Indian Lake whitefish grew faster than did Fidler or Wood Lake whitefish. However, there was a significant difference between the elevations of the growth curves of whitefish from Wood Lake and the three Chruchill River lakes.

	Length-age Regression Formulae (Trip I)
Partridge Breast	Length = 108.8 + 32.5 (age)
Northern Indian	Length = 103.4 + 30.6 (age)
Fidler	Length = 128.7 + 24.7 (age)
Wood	Length = 221.5 + 24.8 (age)

Since the rate of growth of whitefish in Wood Lake was not greater, an early advantage in growth (shown in the back-calculated data) would account for the substantially higher elevation. The apparent growth rate

rate of whitefish in all four lakes of the study area was slower than the average reported for other lakes in the area (Ayles and Koshinsky, MS 1974). However, the y-intercept values were close to those given for lakes in the Churchill River drainage system.

For a given length, whitefish in Northern Indian Lake were heavier than whitefish from the three other lakes. Whitefish in Wood Lake were generally in poorer condition than whitefish in the lower Churchill. The general condition of whitefish in the lower Churchill lakes was comparable to that of whitefish in Southern Indian Lake (Ayles and Koshinsky, MS 1974).

Diet:

The inclusion of algae, trichopterans (caddis flies), and mayfly nymphs (Table 1.4) illustrate the opportunism and seasonality of the whitefish feeding habit. Moreover, the food consumed does not appear to correlate with the composition of the benthic communities of these lakes. *Pontoporeia* was the most abundant zoobenthos species from Fidler, Northern Indian and Wood Lakes (Hamilton and McRae, MS 1974), but it was only a minor item in the food of whitefish. This was a significant departure from the important role that amphipods played in the diet of whitefish in Southern Indian Lake (Ayles and Koshinsky, MS 1974) and other Churchill mainstem lakes (Rawson, 1960).

Catch per unit effort:

The numbers of whitefish caught in gillnets during both trips to each lake is shown in Table 1.5. On the whole, catch per unit effort (C.U.E.) was highest in Fidler Lake (59) which exceeds that reported for Southern Indian Lake (45) by Ayles and Koshinsky, (MS 1974) and is substantially higher than lakes of the upper Churchill (Rawson, 1960). However, catch per unit effort in Wood Lake was only 32-49% that of the three Churchill River lakes.

Implications of diversion on lake whitefish:

Lake whitefish are fall spawners, usually seeking areas of shallow boulders and rock rubble (3-10 feet). The reduced lake levels will destroy present spawning sites, and although new areas of boulder and rock rubble will be present they will be temporarily under a layer of silt which will eventually be cleaned in the new wave-wash zone.

The level reductions predicted during September-November (9-11 feet) will occur during the time when sites are being chosen. Significant changes in water levels at this point in time could disorient whitefish and reduce the numbers that will attempt to spawn. As well, further drawdowns following spawning could expose some spawn, or alter the oxygen levels around others enough to seriously affect egg development.

Increased level fluctuations will decrease the stability of the littoral zone, decreasing the production of benthic fauna and increasing nearshore turbidity. Whitefish are primarily benthic feeders, and a decrease in quantity of benthic organisms (Hamilton and McRae, MS 1974) will undoubtedly be reflected in a further decrease in whitefish product

Table 1.3. Back calculated fork lengths at the time of each annulus formation for each age group of lake whitefish from the Lower Churchill.

Lake	Weighed mean fork length (mm) and increments at each annulus																
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Partridge Breast	82	131	177	219	262	299	331	362	389	415	436	452	463	527	551		
Incr.	82	49	46	42	43	37	32	31	27	26	21	16	11	64	24		
No.	97	97	97	92	85	76	70	62	51	37	18	10	3	1	1		
Northern Indian	66	110	152	192	228	266	299	334	366	395	418	435	462	479	489	501	510
Incr.	66	44	42	40	36	38	33	35	32	29	23	17	27	17	10	12	9
No.	458	458	456	447	382	337	302	253	208	167	98	54	24	6	2	1	1
Fidler	69	113	149	182	217	253	282	311	335	361	377	391	414	444			
Incr.	69	44	36	33	35	36	29	29	24	26	16	14	23	30			
No.	212	212	208	191	174	165	154	143	123	95	59	35	13	4			
Wood	84	139	192	238	280	322	360	384	404	426	446	458	471	485			
Incr.	84	55	53	46	42	42	38	24	20	22	20	12	13	14			
No.	97	97	96	93	91	88	83	72	59	45	26	19	5	3			

Table 1.4. Food of whitefish as percent weight by items from the lower Churchill lakes.

	Partridge Breast	Northern Indian	Fidler	Wood
Amphipods	4.2	7.7	9.6	12.7
Sphaeriids	29.5	11.0	18.8	5.0
Gastropods		0.2	1.5	0.1
Valvatids	2.1	33.1	10.8	9.6
Chironomids	33.0	11.3	24.2	1.1
Ephemeroptera		32.2	23.1	
Trichoptera	27.2	3.0	9.5	37.4
Mysids		0.7		
Ninespine Stickleback		0.4		3.3
Slimy sculpin				1.2
Cyanophyta (Nostoc)				23.0
Miscellaneous	4.0	0.4	2.5	6.6
No. examined	69	415	220	64
% feeding	62	77	61	70

Table 1.5. Catch per unit effort for whitefish on the lower Churchill River lakes.

Lake	Trip I	(lbs)	Trip II	(lbs)	Trip I+II	(lbs)
Partridge Breast	27.5	(57.4)	83.4	(160.2)	38.7	(77.8)
Northern Indian	45.6	(83.6)	27.9	(41.8)	38.3	(66.9)
Fidler	51.5	(70.7)	69.3	(100.2)	58.5	(82.9)
Wood	16.4	(43.8)	21.0	(51.9)	18.7	(47.8)

1.6. NORTHERN PIKE

Age, growth and condition:

The dominant length class in all lakes was approximately 2 inches, which is representative of pike aged 5+ years. The back calculated data (Table 1.6) shows that pike in Wood Lake have a slightly better growth rate, although no significant differences tween lakes or trips in growth rates were found. However, the gr curve for Wood Lake pike did have a higher elevation than any of growth curves for the lower Churchill pike, which suggested a fas growth rate in Wood Lake during the early years of life. On the northern pike in the study area grew better than those reported f other lakes in the Churchill River drainage (Rawson, 1957, 1960; and Atton, 1953; Koshinsky, 1965, MS 1971).

Pike from Partridge Breast Lake were in better condition (than those from either Northern Indian or Fidler Lakes. Pike fro Churchill River lakes appeared to be in better condition than pik Southern Indian Lake (Ayles and Koshinsky, MS 1974) and comparab pike in Lac la Ronge (Koshinsky, MS 1972). With the exceptions Partridge Breast and Wood Lakes, the fish prey found in pike stom reflected the general abundance of these food sources as caught i gillnets (Table 1.7). However, the apparent high consumption of (47.7%) by Partridge Breast pike suggests some selectivity on the

The only significant non-fish items were leeches and mayfl nymphs. This trend differs significantly from the high volumes of non-fish foods observed in pike from other Churchill River drainage lakes (Rawson, 1960; Koshinsky, 1965) and may account for the good growth and condition of these fish.

Catch per unit effort:

Catch per unit effort decreased sharply in all lakes following trip I (Table 1.8), possibly reflecting a wide post-spawning dispersio of pike, a localization in specific habitats or lower activity in late summer. A similar decrease with the progression of summer was noted i certain regions of Southern Indian Lake by Ayles and Koshinsky (MS 197 Catch per unit effort is however, generally higher than those reported from upstream lakes of the Churchill River (Rawson, 1960; Ayles and Koshinsky, MS 1974).

Implications of diversion on northern pike:

Northern pike are spring spawners seeking areas of aquatic and flooded vegetation. The decreased lake levels will make all areas previously ideal for pike spawning unavailable and continued fluctuations following spawning will seriously affect the success of any incubation of pike eggs. Increased annual lake level fluctuations will retard the establishment of new rooted aquatic vegetation and thus prevent the establishment of new areas for pike spawning.

Although pike are primarily fish-eaters, the overall reduction in the food base will ultimately lower the production of northern pike.

Table 1.6. Back calculated fork lengths at the time of each annulus formation for each age group of northern pike from the lower Churchill River lakes.

Lake	Weighed mean fork length (mm) and increments at each annulus											
	1	2	3	4	5	6	7	8	9	10	11	12
Partridge Breast	181	302	403	487	542	578	606	647	733	738		
Incr.	181	121	101	84	55	36	28	41	86	5		
No.	67	65	62	57	51	40	27	12	4	3		
Northern Indian	181	285	376	440	501	536	580	628	666	695	693	709
Incr.	181	104	91	64	61	35	44	48	38	29	-2	16
No.	98	96	90	86	82	68	44	33	23	10	4	3
Fidler	187	297	385	449	500	543	576	611	633	714	819	
Incr.	187	110	88	64	51	43	33	35	52	51	105	
No.	78	78	73	71	65	49	29	16	7	2	1	
Wood	190	328	426	496	553	592	629	668	774	824		
Incr.	190	138	98	70	57	39	28	48	106	50		
No.	71	71	70	68	61	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		

Table 1.7. Food of northern pike as percent weights by items from the lower Churchill lakes.

	Partridge Breast	Northern Indian	Fidler	Wood
Whitefish	19.0	38.6		0
Cisco		22.5	30.9	9.5
White sucker		17.1	38.0	
Longnose sucker				36.7
Burbot	47.7			
Walleye			1.0	
Pike			1.3	
Lake chub	1.3			
Trout-perch		3.2	1.7	8,5
Slimy sculpin		0.8		4.0
Ninespine stickleback	17.9	0.2	0.5	7.5
Unidentified fish	5.1	15.9	22.4	33.0
Ephemeroptera		1.5	1.1	
Hirundinea	3.2		3.1	0.8
Miscellaneous	5.8	0.2		
Number examined	25	202	84	28

Table 1.8. Catch per unit effort for northern pike on the lower Churchill River lakes.

Lake	Trip I	(lbs)	Trip II	(lbs)	Trip I+II	(lbs)
Partridge Breast	29.0	(95.2)	9.7	(34.8)	25.1	(83.1)
Northern Indian	17.8	(105.0)	9.1	(24.6)	14.8	(87.5)
Fidler	27.5	(79.6)	9.7	(25.7)	20.8	(57.7)
Wood	12.6	(47.0)	8.2	(31.6)	10.4	(39.3)

1.7. WALLEYE

Age, growth and condition:

Comparison of back calculated lengths-at-age (Table 1.9) with those of Southern Indian Lake walleye (Ayles and Koshinsky, MS 1974) revealed that walleye were growing at a faster rate in the lower Churchill drainage lakes than in Southern Indian Lake. Also, growth in length was much better than that of walleye in Trout Lake (Koshinsky, MS 1971), or lakes from the upper Churchill (Rawson, 1957b), and comparable to that of Lac la Ronge (Rawson, 1957a).

Age-length data from Trip I indicates that walleye from Wood Lake grew significantly faster than walleye from Northern Indian Lake. However, the growth curve of Northern Indian walleye was significantly higher in elevation than that from Wood Lake again suggesting an early advantage in growth for Northern Indian Lake walleye. The rate of growth of walleye during Trip II was the same for all lakes, but the elevation of the growth curve for walleye from Northern Indian Lake continued to be higher than that from Wood Lake.

Age-length regression formulae were as follows:

	Trip I	Trip II
Northern Indian Lake		
	Length = 351.9+14.0 (age)	Length = 219.6+29.0 (age)
Wood Lake		
	Length = 145.3+38.5 (age)	Length = 197.4+31.9 (age)

In general, walleye from Northern Indian Lake were heavier for a given length than walleye from Wood Lake. Walleye from Fidler Lake were consistently in poorer condition.

Diet:

The exclusive fish diet (cisco, trout-perch, ninespine stickleback, slimy sculpin, and others) is not unlike the diet of Southern Indian walleye, where cisco and/or whitefish were predominant (Ayles and Koshinsky, MS 1974). However, the lack of significant amounts of invertebrates such as mayfly nymphs, leeches, dragonfly nymphs, and amphipods is unique in comparison to lakes of the upper Churchill (Rawson, 1960; Koshinsky, MS 1971), where such items commonly make up 30-80% of the diet of walleyes. This heavy reliance on fish prey may account for the walleye's better growth in the lower Churchill system as compared to the upstream waters.

Catch per unit effort:

The mean catch per unit effort (C.U.E.) was highest in Northern Indian (17) and Wood (12) and lowest in Fidler (4) and Partridge Breast (0.3). It appears that walleye populations in the lower Churchill lakes are low when compared to catch per unit efforts reported from upstream waters such as Southern Indian (Ayles and Koshinsky, MS 1974), Otter, Drinking, Nistowiak and Mountain Lakes (Rawson, 1960).

Implications of diversion on walleye:

Walleye are spring spawners and may seek either lake or streams though it is unlikely that any one walleye is able to spawn in both types of habitat. Lake spawners will have difficulty with new spawning areas until silt from the old lake bottom has been removed in the new wave washed zones. Stream spawners should not be affected by the diversion providing access to the streams does not become impossible.

The general reduction in the food base because of the alteration to the littoral zone will be reflected in an overall decrease in walleye production.

Table 1.9. Back calculated fork lengths at the time of each annulus formation for each age group of walleye from the lower Churchill River lakes.

Lake	Weighed mean fork length (mm) and increments at each annulus									
	1	2	3	4	5	6	7	8	9	10
Northern Indian	118	181	243	304	352	390	415	435	455	517
Incr.	118	63	62	61	48	38	25	20	20	62
No.	91	91	88	87	84	67	45	24	10	1
Fidler	105	162	217	281	323	366	392	428	463	
Incr.	105	57	55	64	42	43	26	36	35	
No.	13	13	13	13	9	6	5	2	1	
Wood	118	178	229	287	333	382	419	448	461	
Incr.	118	60	51	58	46	49	37	29	13	
No.	67	67	63	54	37	24	17	6	3	

1.8. LAKE TROUT

Lake trout were most abundant in Wood Lake, with a catch per unit effort of 6.4 and a composition of 30.6% of the mean catch per unit effort in pounds (Table 1.2). Catch per unit effort for the lower Churchill lakes was quite low; Fidler (0.6) and Northern Indian (0.1). Lake trout caught had a mean length of 25.4 inches and a mean weight of 6.95 pounds. The apparent growth rate appears to be comparable to that reported from Lac la Ronge by Rawson (1961).

Fish prey were the main staple of lake trout. The diet of Wood Lake lake trout illustrated this importance, as suckers, trout-perch and cisco comprised nearly 100% by weight of the food items consumed.

Lake trout seek rocky shoals often in shallower water (minimum one foot) for spawning and although new shoals will undoubtedly be present at the lower lake levels, as in the case of whitefish and walleye, these sites will not be suitable until they are free of silt.

1.9. CISCO

The growth rate of cisco was similar to that of cisco caught upstream in Southern Indian Lake by Ayles and Koshinsky (MS 1974). However, there appeared to be some variability between ciscoes in this region, although the growth data is insufficient for any definite conclusions. The length-weight relationships of ciscoes suggested that those in Northern Indian were in better condition, particularly so in the early summer.

The importance of Mysis (36.2%) and mayfly nymphs (31.6%) in the diet of Northern Indian Lake cisco parallels that of cisco in Southern Indian Lake (Ayles and Koshinsky, MS 1974). Catch per unit effort (C.U.E.) was highest in Northern Indian Lake (4.4), and lowest in Wood (0.5) (Table 1.2). Overall, catch per unit effort was quite low in comparison with upstream lakes such as Southern Indian (Ayles and Koshinsky MS 1974). A possible reason for this might be the high flushing rate of the lower Churchill lakes which does not favour the development of sizeable populations of zooplankters (Patalas and Salki, MS 1974), the usual forage of cisco.

Cisco seek areas for spawning that are very similar to those of whitefish and hence should experience the same problems as described for whitefish. Cisco are primarily zooplankton feeders and, according to Patalas and Salki (MS 1974) the lower Churchill River lakes will decrease in zooplankton production following diversion, decreasing the cisco population further.

1.10. WHITE SUCKER

Suckers were important secondary species in catches from the lower Churchill River lakes. Overall, white suckers were second in numbers only to whitefish. Catch per unit efforts were as follows: Northern Indian (29), Fidler (24), Wood (8), and Partridge Breast (4). The dominant length class of suckers was approximately 16 inches, which according to the data of Churchill Lake (Rawson, 1957b) would make these fish over 5 years of age. The mean length of white suckers caught was 15.1 inches.

White sucker spawn in shallow areas of lakes and in the mouth of streams. New spawning sites in the lakes will have to develop following the removal of the silt in the old lake bed. Spawning sites in streams should not be altered providing access to streams remains available.

White sucker are bottom feeders and the overall reduction in benthic invertebrates (Hamilton and McRae, MS 1974) will be reflected in a general reduction of white suckers.

1.11. LONGNOSE SUCKER

The dominant length class of longnose suckers caught from the lower Churchill was approximately 17-18 inches, which for lakes of the Churchill system could be indicative of fish at least 4 years of age (Rawson, 1957b) or as old as 7 years (Koshinsky, MS 1971) depending on their growth rate. Overall, the catch per unit effort was lower t for white suckers in all lakes except Partridge Breast. Ayles and Koshinsky (MS 1974) reported a mean weight of 2.4 pounds for longnos suckers upstream in Southern Indian, where they had a mean length of 15.6 inches. The mean length of suckers caught in the lower Churchil River lakes was larger (16.5 inches).

Longnose suckers are very similar to white sucker and it is ex that an overall reduction in longnose sucker production will occur as predicted for the white sucker.

1.12. BURBOT

From the catch per unit effort data (C.U.E.), burbot appeared to be most plentiful in Fidler Lake (Table 1.2). With a mean length of 22.3 inches and a mean weight of 3.00 pounds, burbot in the study area seem to be in better condition than burbot from Southern Indian, which h a reported mean length of 22.4 inches and a mean weight of 2.64 pounds (Ayles and Koshinsky, MS 1974).

The diet of burbot consisted of approximately equal proportions of fish (white sucker, trout-perch, slimy sculpin, and others) and non-fish elements (Trichoptera, Plecoptera, mayfly nymphs, and leeches). This relatively high intake of invertebrates is not unusual for burbot (Rawson, 1957b; 1960). However, it contrasts sharply from the burbot in Southern Indian, where fish were exclusively eaten (Ayles and Koshinsky, MS 1974).

Burbot spawn under the ice, usually in shallow areas (1 to 4 feet) Winter drawdowns in the lower Churchill lakes will likely expose incubati eggs to air and ice. Young burbot feed primarily on bottom fauna which are expected to decrease in quantity to two thirds the present level (Hamilton and McRae, 1974) reducing the availability of food for burbot. Adult burbot prey on other species of fish, and the predicted overall decrease in fish production should be reflected in this species as well.

1.13. YELLOW PERCH

Catch per unit effort (C.U.E.) for perch in the lower Churc
was extremely low; Partridge Breast (0.1) and Northern Indian (0.8
The mean length of perch was 6.1 inches, which according to Rawson
(1957b) are fish over 4 years of age, and a mean weight of 2.4 oun
Of two perch examined for stomach contents, both contained mayfly
exclusively. Ayles and Koshinsky (MS 1974) reported that mayfly
were also an important dietary item of perch in Southern Indian, a
with mysids and fish (sculpins).

Perch habitat in the lakes on the lower Churchill River sho
improve, although availability of spawning habitat will remain unc
for a number of years.

1.14. RECOMMENDATIONS

The flow regulation and diversion of the lower Churchill Riv
has serious implications for the fish populations in this region.
most severe effects will be the reduced spawning success of the maj
commercial species (whitefish) and the almost total destruction of
present littoral zone (major feeding and nursery area).

Areas of aquatic and flooded vegetation, formerly available
pike spawning in the spring, will be drastically if not totally redu
For fall spawning coregonids, notably the lake whitefish and cisco,
situation is just as grave. New spawning sites and greater chances
further drawdowns occurring after the spawning period, will lead to
ships for proper egg incubation particularly if oxygen and siltatio
become altered.

The influx of the Churchill River in these lakes has a profou
influence on the internal movement of water in these lakes. It is c
ceivable that if the current structure of the lower Churchill River
were affected by the drastically reduced flows as a result of the di
then the spawning runs and migrations of some species could be disor
particularly if they happen to be homing to specific spawning areas.

Annual lake levels following diversion will fluctuate more th
twice the amount prior to regulation (Brown, MS 1974). Fluctuating
levels greatly affect the stability of the littoral or shallow water
through exposure to air and the scouring action of ice. In Lake Bla
Sweden, for example, the zone of fluctuation contained 70% less bott
fauna than a similar area not subject to fluctuation (Grimas, 1961).

Such zones are also unsuitable for both growth of rooted aqu vegetation and the spawning activities of many fish. The de of the littoral zone due to exposure and water level fluctua substantially reduce the benthos (Hamilton and McRae, MS 19 create inshore turbidities detrimental to plankton productio and Harper, MS 1974). This will undoubtedly have a major i standing crops and availability of food resources to both la adult fish.

The non-availability of preferred spawning areas and as well as a reduced food base will result in drastic reduct the recruitment of fish to these populations and ultimately result in an unviable commercial fisheries and a lost potent for sport fisheries.

In order to prevent the totally negative implications Churchill River diversion, measures are proposed which will lessen the impact of the foregoing development. First, adeq must be channelled through the Churchill River to maintain a of the present current structure, and to insure an adequate nutrients. Second, in order to lessen the drawdown areas an fluctuations, weirs should be installed at the outlets of th maintain and stabilize water levels at or near their present These measures will insure availability of adequate spawning and a sufficient littoral benthic fauna and flora to sustain near present levels.

RAT-BURNTWOOD LAKES

2.1. INTRODUCTION

During 1973 fisheries of eleven lakes in the Rat-Burntwoo drainage were studied to determine species composition, species distribution, growth, food, and condition of fish. These lakes included three lakes (West Mynarski, Central Mynarski, and East Mynarski) on the Reading River, a tributary to Rat River. This r attempts to summarize the data collected and to compare these dat those collected from Southern Indian Lake as well as to those fro Sipiwesk Lake, a Nelson River reservoir.

The lakes on the Rat-Burntwood River Systems are, at prese a series of small lakes within a relatively small watershed. As they represent a biological system with some properties unique fr much larger river system. Following diversion, these lakes on th Burntwood River System (or the diversion route as it can be refer will receive the flow of the Churchill River, and should lose muc the uniqueness and become more similar to Southern Indian Lake. well as receiving the Churchill River, this system will be impoun and one large lake will be created from the many smaller ones. S Lake on the Nelson River has been impounded for approximately 14 It was raised about 10 feet in total increased in area by 7% and periences an average annual drawdown of 4.4 feet. The Rat-Burntwo will be raised as much as 54 feet, will increase in area 300% and drawdown will be as much as 9 feet. Trends which have been observ

occur in Sipiwesk Lake can be expected to occur and to o
extreme form behind the Notigi control structure. Theref
report attempts to take specific aspects from both South
and Sipiwesk Lake and apply them to the Rat-Burntwood sy
diversion and impoundment.

Detailed discussion is limited to the fish specie
importance to the area, with general reference made to th
of fish investigated. Conclusions and recommendations a
information gathered on the three systems (Rat-Burntwood
and Nelson Reservoirs) as well as on information taken f
developments elsewhere.

2.2. METHODS

Fish sampling on the diversion route lakes was similar to that on Southern Indian Lake (Ayles and Koshinsky, 1974) with the following exceptions. All lakes were fished intensively (from 1 to 10 net-nights depending on lake area) at least once. Four lakes, West Mynarski, Central Mynarski, Rat and Notigi, were fished a second time towards the end of the summer season. One standard gang of gillnets was set at each station and the location of stations was chosen to sample different depths and conditions within a lake.

Stomach samples, age determination, back calculation, length-frequency composition, growth rate, condition and catch per unit effort were treated as described in Ayles and Koshinsky (1974).

Throughout the discussion comparison of the present data is made with region two of Southern Indian Lake and with Sipewisk Lake on the Nelson River. These comparisons are considered to be valid for the following reasons. There will be two new, very strong influences on the lakes of the Rat-Burntwood drainage system. The first will be an introduction of nutrient-rich water from the Churchill River. Region two of Southern Indian Lake receives this flow now and will continue to in the future and the ultimate conditions for fish in the new reservoir will be, to some extent, similar to conditions in region two. The second influence will be the establishment of a large reservoir. While a stable reservoir is created a considerable source of nutrients and sediments will be provided to the new lake from inundated vegetation and stabilizing shorelines. Sipiwesk Lake, on the

Nelson River, was flooded in 1960, and information gathered since this date indicates some of the temporary changes which may be expected in the new Notigi Reservoir. Limitations in the use of Sipiwesk Lake as a model for fisheries development do exist. Sipiwesk Lake is on a different river system with different chemical and physical properties and there is a lack of pre-impoundment information concerning this lake to establish positively which changes have occurred as a result of the impoundment.

2.3. SPECIES COMPOSITION

Fish species found within the diversion route lakes in 1973 are listed in Table 2.1. The species list for Southern Indian Lake and Sipiwesk Lake are included for comparison. The fish crew recorded one species of cisco, *Coregonus artedii*, however, as was the case with cisco in Southern Indian Lake, more than one species may be present under our general heading of lake cisco.

Relative to the species list for Southern Indian and Sipiwesk Lakes, the species list for the diversion route lakes appears to be quite sparse. This could be the result of incomplete sampling but is more likely related to the size of the drainage system and the diversity of habitat within the drainage system. Following diversion, species that are not present now within the diversion route but are in Southern Indian Lake, will be introduced to these lakes and it is expected that they will become established.

le 2.1. Occurrences of fish species in 11 lakes on the Rat-Burntwood River system (1973), and in Southern Indian Lake (1972) and Sipiwesk Lake (1973).

	Lake whitefish (*Coregonus clupeaformis*)	Cisco (*Coregonus artedii*)	Longnose sucker (*Catostomus catostomus*)	White sucker (*Catostomus commersoni*)	Redhorse sucker (*Moxostoma aureolum*)	Yellow walleye (*Stizostedion vitreum*)	Sauger (*Stizostedion canadense*)	Yellow perch (*Perca fluviatilis*)	Northern pike (*Esox lucius*)	Burbot (*Lota lota*)	Goldeye (*Hiodon alosoides*)	Mooneye (*Hiodon tergisus*)	Spot-tail shiner (*Notropis hudsonius*)	Lake shiner (*Notropis atherinoides*)	Blacknose shiner (*Notropis heterolepis*)	Ninespine stickleback (*Pungitius pungitius*)	Slimy sculpin (*Cottus cognatus*)	Mottled sculpin (*Cottus bairdii*)	Spoonhead sculpin (*Cottus ricei*)	Iowa darter (*Etheostoma exile*)	Johnny darter (*Etheostoma nigrum*)	Trout perch (*Percopsis omiscomaycus*)	Brook stickleback (*Culaea inconstans*)	Freshwater drum (*Aplodinotus grunniens*)	Longnose dace (*Rhinichthys cataractae*)	Lake chub (*Couesius plumbeus*)
ett	x	x		x		x		x																		
ichigamu	x	x		x		x	x	x	x	x			x	x				x				x				
sakuwigamak	x	x		x		x	x	x	x																	
	x	x	x	x		x	x	x	x	x			x	x		x	x					x				
Mynarski	x	x				x		x	x																	
ral Mynarski	x	x				x		x	x	x			x	x		x	x					x				
Mynarski	x	x				x		x	x				x	x			x									
gi	x	x		x		x	x	x	x	x			x			x	x					x	x			
su	x	x		x		x	x	x	x	x			x				x									
epoint	x	x		x		x	x		x																	
watim	x	x				x	x	x	x																	
hern Indian	x	x	x	x		x	x	x	x	x	x		x			x	x		x	x		x	x		x	x
wesk	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x		x	x	x

2.4. FISH PRODUCTION

The catch per unit effort (C.U.E.) combined with mean weight of a fish species should reflect the production of a species within a lake, or portion of a lake. This value has been calculated for each of the major species (other than suckers) in each of the Rat-Burntwood lakes and has been compared to the same values from region two of Southern Indian Lake.

Lakes within the diversion route system can be divided into two groups by their production (Table 2.2); the Rat-Burntwood River mainstem lakes and the Reading River lakes (the three Mynarskis). The Rat-Burntwood lakes appear to be moderately productive ranging from a low value of 80.8 to a high of 185.7. The Mynarski Lakes, on the Reading River appear to be very productive with values that exceed by a third, the value determined for region two in Southern Indian Lake. Although region two of Southern Indian Lake has been commercially fished consistently for the past two decades and it is difficult to compare these lakes closely, primary production, a commercially unexploitable parameter, is also higher in the Mynarski Lakes (Hecky and Harper, 1974). It would appear that these lakes are receiving abundant nutrients from surrounding clays; and, because of the low flows, turbidity is low and utilization of these nutrients is high. The high primary production is reflected in the high production of fish.

Impact of diversion and impoundment on fish production:

The introduction of the Churchill River will eventually make conditions in the new reservoir similar to Southern Indian Lake and this should ultimately increase production of all fish species in the diversio route lakes. However, until the new reservoir is firmly established and shorelines have stabilized, fish production will depend on nutrients and sediments released from the inundated land, nutrients contributed from the Churchill River, oxygen demand of drowned organic materials and availability of suitable fish habitat. Fish habitat will be excellent for some species (pike and perhaps goldeye) but will be poorer for others (whitefish and cisco).

Until shoreline stabilization has occurred the overall increase in fish production on a per-unit-area basis will be the result of increas in production of some, not all, of the species present. In Sipiwesk Lake on the Nelson River production has approximately doubled in the past seven years. However, the commercial fish records indicate that during this period the pike harvest has increased considerably, the walleye harvest slightly, and the whitefish harvest has decreased (section 3).

Table 2.2. Catch per unit effort (pounds) of seven species of fish from 11 lakes in the Rat-Burntwood drainage and from region 2 of Southern Indian Lake.

	Issett	Karsakuwigamak	Pemichigamau	Rat	West Mynarski	Central Mynarski	East Mynarski	Notigi	Wapisu	Threepoint	Wuskwatim	Southern Indian (2)
Whitefish	67.4	17	6.1	12.6	47.4	32.6	91.3	15.5	5.9	3.6	14.6	113
Walleye	30.2	45.7	65.1	59.4	124	118.8	41.1	47.1	52.8	169.6	47.5	7
Pike	63.9	67.7	73.0	49.9	64.8	56.3	44.7	25.2	8.1	7.5	13.2	52
Cisco	23.4	1.8	3.5	41.8	37.6	169.7	123.2	3.2	6.3	1.4	8.9	18
Sauger	-	1.4	1.8	2.7	-	-	0.1	21.3	5.4	-	14.9	1
Burbot	-	-	-	1.1	-	7.4	-	-	-	3.6	5.1	9
Perch	-	2.3	1.0	0.3	58.6	1.5	2.3	0.8	2.3	-	4.7	-
Total	184.9	135.9	150.5	167.8	332.4	386.3	302.7	113.1	80.8	185.7	108.9	200.00

2.5. WHITEFISH

The information derived from back-calculation of whitefish age suggests that, in general, all whitefish in the diversion route lakes had a similar rate of growth (Fig. 2.1). The obvious exception is West Mynarski Lake with an apparent early, rapid rate of growth followed by a much slower rate for the mature fish (6+ years). The statistical analysis of the growth curves correspond to the observations made on the back-calculations; for their age, whitefish from West Mynarski Lake were significantly longer than whitefish from other diversion route lakes. The growth curves for the lower diversion route lakes (Rat, Notigi, Wapisu, Threepoint and Wuskwatim) appear to be statistically better than growth curves of the upper diversion route lakes, but this is more likely related to the fact that whitefish from the lower diversion route had a lower mean age than whitefish from the other lakes rather than the fact that rate of growth is superior.

Mean age of whitefish varied, significantly, among the lakes of the diversion route (Table 2.3). It is difficult to suggest an explanation by generalizing the data. The lakes with lower mean ages (Pemichigamau, Threepoint, Wuskwatim and Rat) are lakes that had a low yield of whit fish which could be either the result of poor conditions in the lake or perhaps the result of a commercial fishery present. Karsakuwigamak, Notig and Wapisu Lakes had a low yield of whitefish, but have had little or no fishing pressure in recent years (Weagle, MS 1974), and mean age was high

The mean age of whitefish from all diversion route lakes was as high or higher than mean age of whitefish from either Southern Indian Lake or Sipiwesk Lake, two intensively fished whitefish lakes.

The condition of whitefish throughout the diversion route lakes (condition factor, Table 2.3) was better than average when compared with values given by Carlander (1969). The slopes of the condition regressions, when compared with those from region 2 of Southern Indian Lake (Table 2.4) suggest at first glance that whitefish from the diversion route are in better condition. However, when the intercepts are also considered it would appear that mature fish from both systems are similarly in good condition. Condition of whitefish in an established reservoir, (Sipiwesk) was similar to condition in the existing lakes of the Rat-Burntwood Rivers.

Food:

Food of the whitefish from the diversion route lakes (Table 2.5) was similar in composition to whitefish food from Southern Indian with the exception that sphaeriids superseded amphipods in relative importance. Sphaeriids were more plentiful than amphipods in all lakes except West Mynarski (Hamilton and McRae, MS 1974) and it was only in West Mynarski that amphipods were the dominant food item. Sphaeriids are not considered to be as "ideal" as amphipods as a dietary item for whitefish and therefore it is not surprising that where amphipods are dominant (West Mynarski) the whitefish have an excellent rate of growth and are in good condition.

C.U.E. for whitefish:

Catch per unit effort (pounds) of whitefish for the diversion route lakes was considerably lower than for Southern Indian Lake but similar and in some examples greater than C.U.E. of whitefish for Sipiwesk Lak (Table 2.3). Both Southern Indian and Sipiwesk Lakes have been commercially fished much more extensively than the Rat-Burntwood Lakes and one might expect to find the C.U.E. for these two lakes to be simi to less productive lakes that have not undergone extensive commercial fishing. The whitefish C.U.E. for Southern Indian Lake suggests that Southern Indian Lake is considerably more productive of whitefish than diversion route lakes at present.

Impact of diversion and impoundment on whitefish:

The diversion of the Churchill River through the Rat-Burntwood Lakes with its impoundment will result in considerable alteration of t whitefish habitat. As outlined by Hecky and Harper (MS 1974), nutrie availability will be similar or somewhat increased. However, until sh line stabilization occurs primary productivity will be somewhat lower than that presently found in Southern Indian Lake north of region two. Benthic invertebrates, in particular amphipods, should increase in ava bility and hence whitefish should respond with increased growth rates enhanced conditions. It is suggested that young whitefish are sight feeders (Ensele, 1963) and increased turbidity, particularly in the shallow areas, could decrease feeding efficiency, slowing growth durin the early development.

Success of whitefish spawning will be the immediate factor whic determines initial productivity of whitefish in the Rat-Burntwood Lake Whitefish spawning habitat will be restricted to those areas appearing now as rock outcrops until shoreline stabilization occurs and clear roc areas are available at the optimum depths. Whitefish production, on a per-unit-area basis, will increase as spawning habitat is established under the new conditions.

Following shoreline stabilization whitefish production, growth and condition should stabilize at a point similar to or slightly better than is found in Sipiwesk Lake presently.

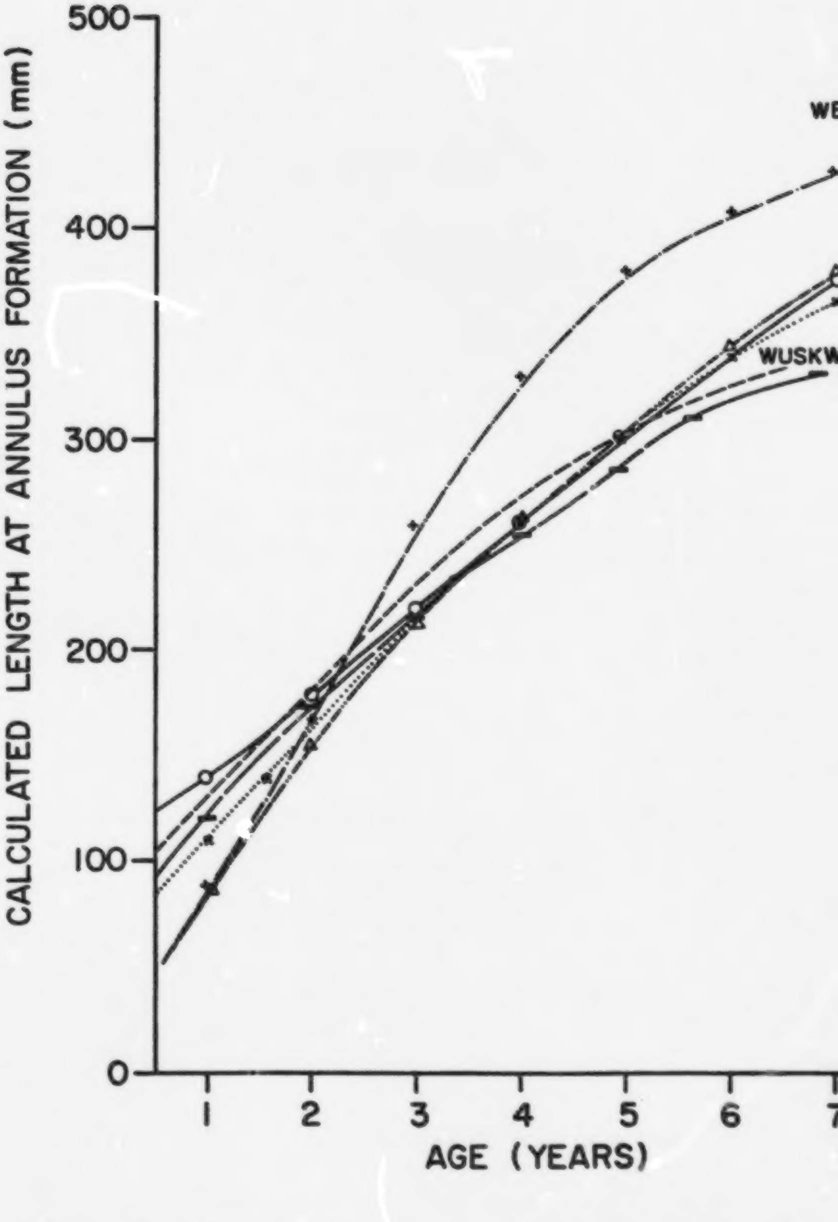

Figure 2.1 Growth rate, derived from back-calculated da
whitefish from 6 lakes of the Rat-Burntwood
1973.

Table 2.3. Catch per unit effort, condition, mean length, mean weight, and mean age of whitefish from 11 lakes on the Rat-Burntwood Rivers (1973) and from Southern Indian (1972) and Sipiwesk Lakes (1973).

	C.U.E. (pounds)	Condition factor	Mean Length (inches)	Mean Weight (pounds)	Mean Age (years)
Issett	67.4	1.65	15.7	2.3	7.1
Karsakuwigamak	17.0	1.86	15.3	2.4	7.3
Pemichigamau	6.1	1.86	14.7	2.1	5.7
Rat	12.6	1.92	14.9	2.3	6.4
West Mynarski	47.4	2.04	16.3	3.2	7.2
Central Mynarski	32.6	1.69	17.0	3.0	-
East Mynarski	91.3	1.39	16.6	2.3	7.6
Notigi	15.5	2.19	12.9	1.7	7.1
Wapisu	5.9	1.93	13.2	1.6	7.4
Threepoint	3.6	1.56	9.6	0.5	5.4
Wuskwatim	14.6	1.66	11.0	0.8	5.8
Southern Indian (region 2)	113.0	1.52	12.6	1.1	5.7
Sipiwesk	13	1.97	13.1	1.6	5.2

Table 2.4. Formulae for regression coefficients for whitefis
8 lakes in the Rat-Burntwood drainage and from Sc
Indian and Sipiwesk Lakes.

Issett	Log weight = -5.169 + 3.15 (log age
Kasakuwigamak	Log weight = -5.634 + 3.341 (log ag
Rat	Log weight = -5.820 + 3.394 (log ag
West Mynarski	Log weight = -4.340 + 2.844 (log ag
Central Mynarski	Log weight = -5.285 + 3.186 (log ag
East Mynarski	Log weight = -5.611 + 3.296 (log ag
Notigi	Log weight = -5.825 + 3.402 (log ag
Wuskwatim	Log weight = -5.318 + 3.199 (log ag
Southern Indian (region 2)	Log weight = -4.29 + 2.79 (log age)
Sipiwesk	Log weight = -5.66 + 3.35 (log age)

Table 2.5. Food of whitefish as percent weight by items from 11 lakes on the Rat-Burntwood River system, 1973.

	Issett	Kaksakuwigamak	Pemichigamau	Rat	West Mynarski	Central Mynarski	East Mynarski	Notigi	Wapisu	Threepoint	Wuskwatim
Amphipods					64.3		2.1	0.4			
Sphaeriids		37.8	64.9	85.7	9.9	0.8	1.5	65.1	2.4	94.2	51.7
Gastropods	21.4	5.4			6.4	14.3	1.9	0.2	0.2		0.8
Chironomids	86.0				1.2	99.2	5.0	0.1			0.1
Corixids		+	0.1	0.2	0.9			4.1			0.2
Mayflys		0.1					48.2	22.4		5.8	14.2
Valoatids	9.3	40.7	22.4	11.7	17.3		9.3	0.1	0.2		0.1
Tricopterans	4.7	+	7.2	1.4	+		12.7	4.9			13.7
Ostracods				0.3			6.9	0.1	97.1		19.2
Miscellaneous				0.7	+			0.9	.1		
Number examined	2	22	12	17	14	8	38	21	6	6	35

2.6. WALLEYE

Growth curves, determined from back-calculated age information (Fig. 2.2), suggest that, with the exceptions of Threepoint and Wuskwatim Lakes, all walleye on the Rat-Burntwood Lakes were growing at approximately similar rates. A statistical analysis of the growth information confirmed that the growth rate of walleye from Wuskwatim was significantly better than the growth rate of walleye from any other diversion route lake. The growth rate of walleye from Threepoint was not significantly different than from other lakes, however it is apparent that there is an early advantage for walleye in this lake that is not lost in later growth. Walleye in Wapisu Lake also had significantly faster growth than most other diversion route lakes suggesting that it is these lower Rat-Burntwood lakes which provide the more optimum condition for good growth.

Mean age of the sampled walleye populations varied throughout the system (Table 2.6). In general, the upper diversion route lakes contained walleye with a mean age of approximately 5 years and it was the lower lakes of the diversion route (Notigi, Threepoint and Wuskwatim) that contained walleye of a significantly younger age. Walleye in these lakes may be being taken in domestic gillnets and hence the mean age of the population appears to be similar to the mean age of populations of walleye commercially exploited (Southern Indian and Sipiwesk Lakes).

The condition of walleye (condition factor, Table 2.6) from Threepoint and West Mynarski Lakes was as good as the condition of walleye from Southern Indian Lake. All other walleye from the diversion route lakes did not appear to be in as good condition as those taken from Southern Indian, however, they are similar to the condition of walleye from other lakes in northern latitudes (Scott and Crossman, 1973).

Food:

Fish were of major importance in the diet of walleye in the diversion route lakes (Table 2.7). In those lakes with better than average growth rate and condition fish were the dominant food item with invertebrates occurring infrequently. This parallels results from Southern Indian Lake (Ayles and Koshinsky, 1973) but is different from other upstream Churchill lakes where invertebrates are of greater importance (Koshinsky, 1970).

Catch per unit effort:

The catch per unit effort for walleye was excellent in all diversion route lates (Table 2.6) exceeding C.U.E.'s for whitefish from these lakes. Although production is very high most walleye were taken in the small mesh sizes of the experimental gillnets (1 1/2 to 2 3/4 inches) making them unavailable to the commercial fishery.

Impact of the diversion and impoundment on walleye:

Walleye production on a per unit area basis, could possibly decline, particularly during the early phases of the reservoir establishment. The availability of spawning habitat is questionable. Streams known to be heavily used by spawning walleye (e.g. Reading River) will be entirely inundated and others which may be used at present (e.g. Suwanee River) will have important rapids and riffle areas inundated. Walleye will most likely adapt to new spawning areas but the initial success is difficult to predict.

Food for walleye should remain as abundant, or perhaps become even more plentiful as zoobenthos production increases (Hamilton and McRae, 1974). As well, walleye favour more turbid lakes with Secchi disc readings of 1-2 meters (Scott and Crossman, 1973). Such conditions should be abundant in the new reservoir.

Mature walleye seek areas of quickly moving water as spawning sites. Downstream from Notigi such conditions will be created in the tailrace of the Notigi control structure and an excellent tailrace fishery for walleye could eventually be created.

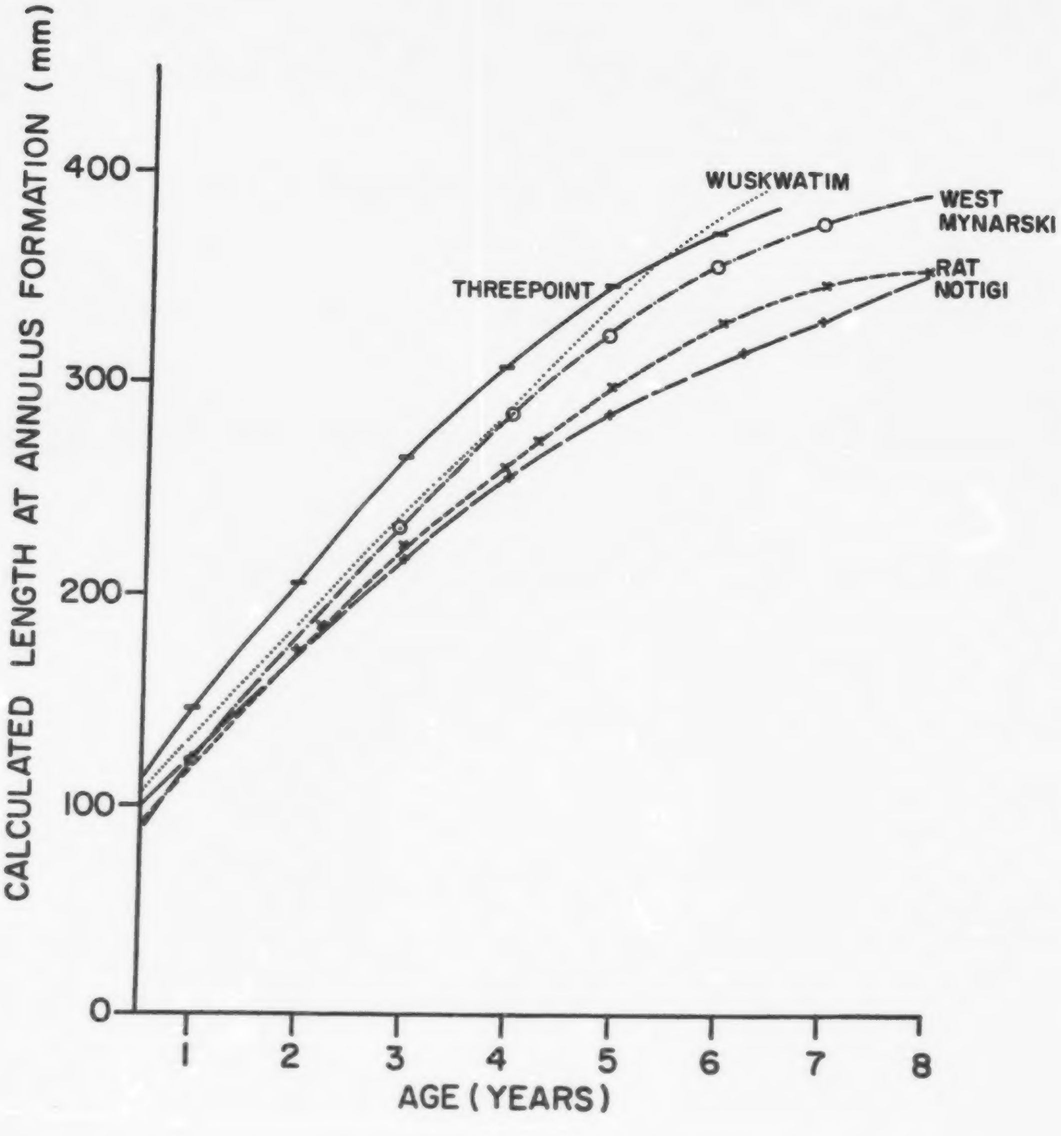

Figure 2.2 Growth rate, derived from back-calculated data, of walleye from 5 lakes of the Rat-Burntwood River System, 1973.

Table 2.6. Catch per unit effort, condition, mean length, mean weight, and mean age of walleye from 11 lakes on the Rat-Burntwood Rivers (1973), and from Southern Indian (1972) and Sipiwesk Lakes (1973).

	C.U.E. (pounds)	Condition factor	Mean Length (inches)	Mean weight (pounds)	Mean age (years)
Issett	30.2	1.10	13.6	1.0	5.1
Karsakuwigamak	45.7	1.04	13.4	0.9	5.1
Pemichigamau	65.1	0.95	13.8	0.9	5.6
Rat	59.4	0.97	14.2	1.0	5.4
West Mynarski	124.0	1.15	15.0	1.4	5.3
Central Mynarski	118.8	1.06	14.2	1.1	-
East Mynarski	41.1	1.01	16.0	1.5	7.1
Notigi	47.1	1.06	12.8	0.8	4.7
Wapisu	52.8	1.03	12.9	0.8	5.4
Threepoint	169.6	1.13	12.5	0.8	4.1
Wuskwatim	47.5	0.91	11.5	0.5	4.6
Southern Indian (region 2)	7	1.13	12.6	0.8	4.3
Sipiwesk	15	1.48	11.9	0.9	4.6

Table 2.7. Food of walleye as percent weight by items from 11 lakes on the Rat-Burntwood River system, 1973.

	Karsakuwigamak	Pemichigamau	Rat	West Mynarski	Central Mynarski	East Mynarski	Notigi	Wapisu	Threepoint	Wuskwatim
Fish*	6.01	9.96	21.9	81.23	6.49	72.08	27.16	45.36	70.04	72.27
Crayfish			9.15					0.40		.32
Mayflys	13.0	25.14	12.56		0.28	3.87	1.62	3.49		
Chironomids			.01		0.37		0.10	.05		
Sphaeriids			.01							
Mysids	1.6	24.27	3.94		22.92	11.39				
Corixids										
Tricoptera		.02	.08	.14		0.12	0.14	.04		
Unidentified	79.39	40.61	52.35	18.63	69.84	12.54	70.98	50.66	29.96	27.41
Number examined	24	33	39	13	22	11	58	60	33	8

* Nine-spine stickleback, sculpin, perch, trout-perch, cisco, whitefish, sucker, and spot-tail shiner.

2.7. PIKE

Growth of northern pike appeared to be quite similar throughout the Rat-Burntwood lakes with the exception of the three lower lakes, Wapisu, Threepoint and Wuskwatim which contained populations of young, slower growing pike (Fig. 2.3). The population of pike in these three lower lakes differed from the others in production as well. Catch per unit effort, in pounds, for all other lakes in the system was similar to those of Southern Indian and Sipiwesk while C.U.E. for Wapisu, Threepoint and Wuskwatim was considerably lower (Table 2.8). As was the case for walleye and whitefish, there is not a strong commercial fishery for this species in these lakes (Weagle, 1974) however, because of these lakes' close proximity to the residents of Nelson House there is likely heavy pressure from a domestic fishery.

Impact of diversion and impoundment on northern pike:

The change to the aquatic ecosystem that the diversion and impoundment will create will positively influence the existing northern pike population.

Ideal spawning habitat will be created by the increased water levels and flooding of shoreline vegetation. Provided drawdown within the reservoir does not occur during incubation of pike eggs (June and early July) the success of pike spawning should increase measureably. Food during the early stages of development (large zooplankton and benthos should not be a limiting factor, and food during later stages and for the adults (fish) should be present in ample quantities.

For a number of years following diversion and impoundment northern pike will increase in production by increasing the numbers of the small to medium sized pike. This will endure until shoreline stabilization has occurred when production will drop, but it should drop to a somewhat higher level than is present now.

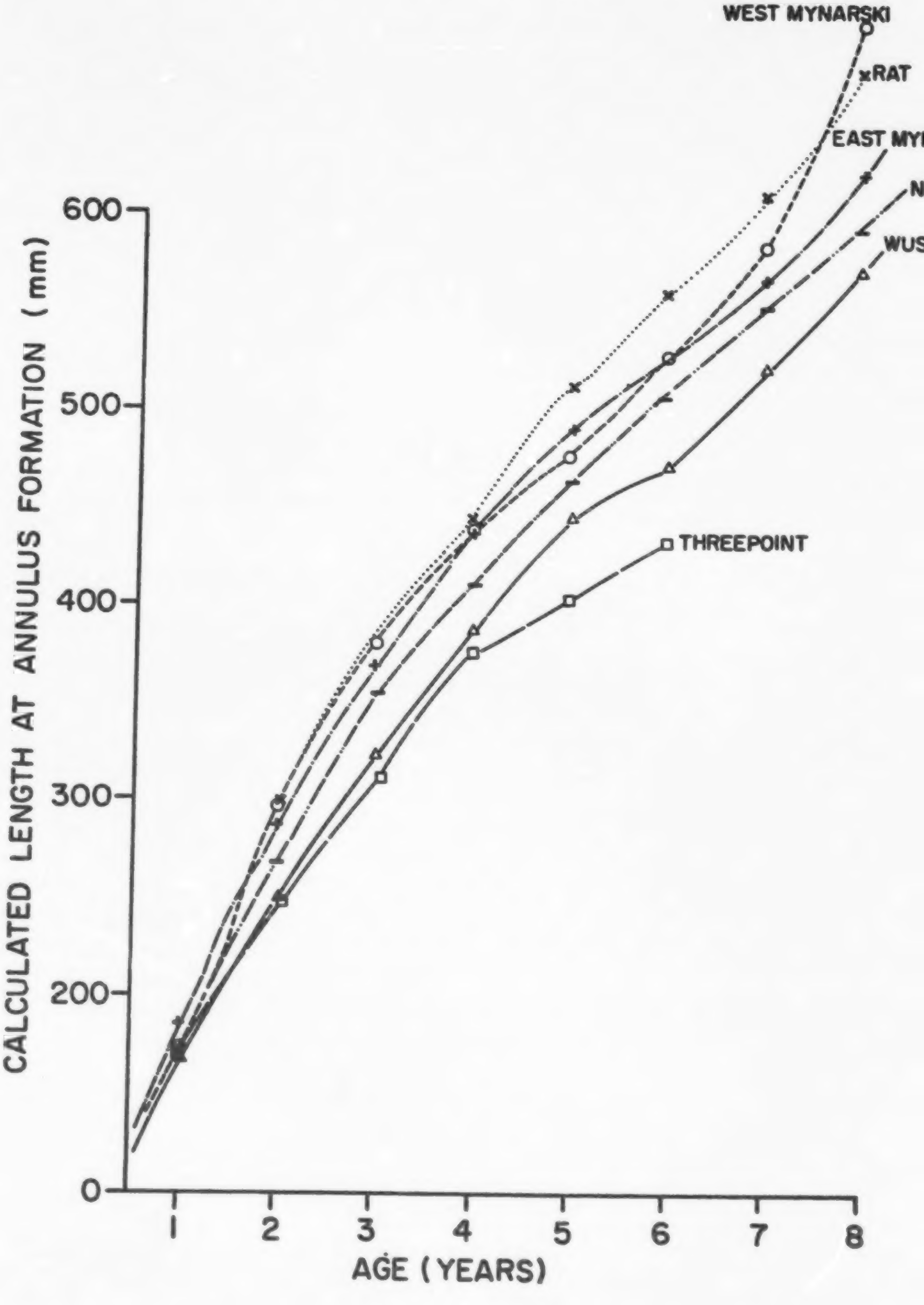

Figure 2.3 Growth rate, derived from back-calculated data, of northern pike from 6 lakes of the Rat-Burntwood River System, 1973.

Table 2.8. Catch per unit effort, condition, mean length, mean weight, and mean age of northern pike from 11 lakes on the Rat-Burntwood Rivers (1973), and from Southern Indian (1972) and Sipiwesk Lakes (1973).

	C.U.E. (pounds)	Condition factor	Mean length (inches)	Mean weight (pounds)	Mean age (years)
Issett	63.9	0.85	24.5	4.5	7.7
Karsakuwigamak	67.7	1.16	20.7	3.7	6.7
Pemichigamau	73.0	0.98	19.9	2.4	5.3
Rat	49.9	0.80	22.7	3.4	6.9
West Mynarski	64.8	0.74	16.7	1.3	4.5
Central Mynarski	56.3	0.93	20.5	2.9	-
East Mynarski	44.7	0.76	22.2	3.0	6.6
Notigi	25.2	0.85	22.3	3.4	7.1
Wapisu	8.1	0.74	16.2	1.1	3.6
Threepoint	7.5	0.69	15.4	0.9	6.5
Wuskwatim	13.2	0.85	20.6	2.7	6.9
Southern Indian (region 2)	52	0.65	21.1	2.2	5.3
Sipiwesk	32	0.89	22.9	3.8	

2.8. CISCO

Cisco were found throughout the Rat-Burntwood lakes in vary quantities (Table 2.2). They were most prevalent in the very productive Mynarski Lakes. Following diversion and impoundment ci will likely increase in production on a per-unit-area basis. Alth availability of suitable spawning grounds is questionable, ciscoes been known to spawn pelagically in 30-40 feet of water (Scott and Crossman, 1973) and perhaps old spawning areas may be utilized. F of very young ciscoes will decrease (zooplankton: Patalas and Sal 1974) but food of the adult cisco will increase (benthos: Hamilto McRae, 1974).

2.9. SAUGER

Sauger were not prevalent in the Rat-Burntwood lakes (Table The present habitat for saugers in these lakes is good, but followi diversion it should become even better. Sauger prefer shallow lake rich in colloidal clay suspension (Scott and Crossman, 1973); these conditions will undoubtedly exist at least for a number of years. sauger are at the northern extreme of their range and it is not exp that production will increase exceptionally.

2.10. GOLDEYE

Goldeye were not found to be present in the Rat-Burntwood lake in 1973. However, they are known to be present in Southern Indian Lake and with the diversion of the Churchill water they will likely be introduced to the newly formed reservoir. The reservoir will conta at least for a number of years, habitat which is considered to be idea for goldeye, i.e. quiet, turbid bays, marshes and muddy shallows (Scot and Crossman, 1973), and goldeye should become successfully establishe

2.11. WHITE AND LONGNOSE SUCKERS

Longnose sucker was taken only from Rat Lake in 1973 and its abundance in the new reservoir will likely not increase (on a per-unit area basis) until the shorelines have stabilized and the reservoir cleared. Longnose sucker prefer cool, clear, deep lakes and these conditions will not likely exist in the Rat-Notigi Reservoir for some time.

White sucker prefer the warmer shallow areas of lakes and are known to reproduce well in new reservoirs. They were more plentiful in the Rat-Burntwood lakes than were longnose suckers and it is expect that they will produce well in the new reservoir.

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2.12. YELLOW PERCH

Yellow perch are in moderate supply in the Rat-Burntw at present (Table 2.2). It is unlikely that production of y will increase following diversion because both increased flo and increased turbidity will create unfavourable conditions species.

2.13. RECOMMENDATIONS FOR MITIGATION

Faced with such extensive changes to the environment it is difficult to recommend mitigation measures that would be meaningful. Clearing for whitefish spawning, as has been recommended for Southern Indian Lake, would be unreasonable in the Rat-Notigi Reservoir. No clearing for walleye spawning areas is being recommended because not enough is known about where the walleye will attempt to spawn following inundation of their existing spawning beds.

Many of the questions raised by this hydroelectric development have been impossible to answer adequately because the environmental implications of developments of this size and at this latitude are simply not well enough understood. One of the most important questions concerns the effects of various timber clearing practices on erosion processes, shoreline stabilization rates, and ultimately the biological productivity of the inundated areas. As previously communicated, experimental clearing of selected areas in the Notigi Reservoir would provide a real opportunity to produce some definitive answers to critical questions concerning clearing practices. This knowledge would also be very applicable to future reservoirs to be constructed elsewhere in northern Canada.

Potentially, the greatest benefit of the Lake Winnipeg, Churchill and Nelson Rivers Study is that there is now a wealth of background information that can be compared with information gathered in follow-up studies. Every effort should be made to ensure that resources are made available to adequately monitor major changes that do occur in the altered areas.

NELSON RIVER LAKES

3.1. INTRODUCTION

A fisheries survey was conducted on the Nelson River lakes (Fig. 1 C) of Cross, Sipiwesk, Split, and Kettle Reservoir from June 1973 to August 1973. The Nelson River lakes are to be affected by Lake Winnipeg regulation and the Churchill River diversion and this survey was conducted to augment existing data as well as to procure data from the recently flooded Kettle Reservoir (1970) and Sipiwesk Lake (1960). These data include estimates of relative sizes of fish populations, fish species composition, growth, condition, and food. The following report will attempt to summarize the data available.

Cross Lake has been physically and morphometrically described by Driver and Doan (MS 1972). Five experimental gillnet sets were made from July 2-10, 1973 in different areas of the lake.

Sipiwesk Lake has been physically and morphometrically described by Schlick (MS 1968). Eight experimental gillnet sets were made throughout the lake from June 9-21, 1973. The level of Sipiwesk Lake was raised in 1960 approximately 10 feet by the Kelsey generating station.

Split Lake has been physically and morphometrically described by Schlick (MS 1968). There were 6 experimental gillnet sets made from August 3-8, 1973. At Split Lake the water of the Churchill River diversion will discharge from the Odei River.

Kettle Reservoir has been physically described by Crowe (MS 1973). No morphometric data was presently obtainable. Eight experimental gillnet sets were made from August 12-24, 1973. Six sets were made along the mainstream of the Nelson River and two in back-flooded Big and Little Moose Lakes. The fish from Big and Little Moose Lakes were found to be significantly different than the other sets and therefore these data were analyzed separately and called Moose Lake. Moose Lakes, although flooded, are essentially isolated from the rest of the reservoir by a narrow creek; they appear almost completely unaffected by water of the Nelson River mainstream.

3.2. METHODS

The methods used (fish sampling, stomach samples, age determination, back-calculations, length-frequency, growth rate, condition, and catch per unit effort) are similar to those described by Ayles and Koshinsky (1974) with the following exceptions; no Swedish nets were set, a spot poison was made near each set, lengths only were taken on suckers, and nine meshes were used in a standard gang of nets. In order to accommodate the five mesh sizes used by previous provincial government studies and those used by other fishery crews and Ayles and Koshinsky (MS 1974) on Southern Indian Lake, a standard gang incorporating all mesh sizes was devised. The resulting nine meshes were strung in the following order: 3.0 inch, 2.0 inch, 3.75 inch, 4.75 inch, 5.25 inch, 1.5 inch, 4.25 inch, 3.5 inch, and 2.75 inch. This system facilitated comparison with previous studies as well as other fisheries studies carried out on the Rat-Burntwood system, the lower Churchill River system, and Southern Indian Lake.

Limitations in sampling procedure were encountered at Kettle Reservoir. Since all gillnet sets were bottom sets, they could only be set in areas of pre-flood river and lake beds. This put the six mainstream Nelson River sets in extremely deep water (15-25 m) and as a result it is not known whether a very representative sample of the fish was obtained.

3.3. FISH FAUNA

A wide diversification of species was encountered on the upper Nelson River lakes. A complete species list is recorded in Table 3.1. The most notable differences from previous studies is the presence of lake chub,shorthead redhorse suckers, and freshwater drum. In all these lakes there is the possibility that mooneye (*Hiodon tergisus*) might also exist. Preliminary data analysis indicated the possibility of two species in the Hiodontidae family in this area. However, for the purposes of this report no differentiation has been made.

Table 3.1. Occurrence of fish species in four upper Nelson River lakes drainage basin.

	Lake whitefish (*Coregonus clupeaformis*)	Cisco (*Coregonus artedii*)	Yellow walleye (*Stizostedion vitreum vitreum*)	Northern pike (*Esox lucius*)	White sucker (*Catostomus commersoni*)	Longnose sucker (*Catostomus catostomus*)	Redhorse sucker (*Moxostoma macrolepidotum*)	Sauger (*Stizostedion canadense*)	Burbot (*Lota lota*)	Lake sturgeon (*Acipenser fulvescens*)	Yellow perch (*Perca flavescens*)	Lake chub (*Couesius plumbeus*)	Longnose dace (*Rhinichthys cataractae*)	Iowa darter (*Etheostoma exile*)	Johnny darter (*Etheostoma nigrum*)	Fathead minnow (*Pimephales promelas*)	Log perch (*Percina caprodes*)	Mottled sculpin (*Cottus bairdi*)	Slimy sculpin (*Cottus cognatus*)	Blacknose shiner (*Notropis heterolepis*)	Emerald shiner (*Notropis atherinoides*)	Spottail shiner (*Notropis hudsonius*)	Ninespine stickleback (*Pungitus pungitus*)	Trout perch (*Percopsis omiscomaycus*)	Goldeye (*Hiodon alosoides*)	Brook stickleback (*Culaea inconstans*)	Freshwater drum (*Aplodinotus grunniens*)	Blacksided darter (*Percina maculata*)	River darter (*Percina shumardi*)	River shiner (*Notropis blennios*)	Blacknose dace (*Rhinichthys atratulus*)
Cross Lake	x	x	x	x	x	x	x	x	x	x[a]	x	x	x	x	x	x		x	x	x	x[a]	x	x		x	x[a]					
Sipiwesk Lake	x	x	x	x	x	x	x	x	x	x[c]	x	x	x	x	x		x[b]	x	x[b]	x	x	x		x	x	x					
Split Lake	x	x	x	x	x	x	x	x	x	x[d]	x	x	x	x	x		x	x	x		x[b]	x		x[b]	x		x[b]	x[b]	x[b]	x[b]	x[b]
Kettle Reservoir	x	x	x	x	x	x	x	x	x		x	x	x	x	x			x	x			x									

a. Koshinsky MS, 1973. b. Schlick MS, 1968. c. personal observation of local fish catch, 1973. d. commercial catch records.

3.4. COMMERCIAL FISHERY

Cross Lake

The Cross Lake commercial fishery has been outlined to 1971 by Koshinsky (MS 1973). The data have been reproduced including 1972 and 1973 in Fig. 3.1.

Sipiwesk Lake

From the commercial records Sipiwesk has been fished in both summer and winter since 1944-45. The summer limit is presently 100,000 pounds and the winter limit is 120,000 pounds. The last recorded winter fishery operated in 1969-70. The winter fishery has averaged a yield of 161.7 cwt over 18 seasons. The fishery has been primarily a summer operation with an average yield of 809.5 cwt over 26 seasons. Commercial data for the summer fishery since 1954 is presented in Fig. 3.2. The lake was closed due to mercury in 1971 and has remained closed to walleye. The commercial fish yield for the summer fishery in the last 10 years is 0.83 pounds per acre. Since 1960 when the Kelsey dam raised the level of Sipiwesk Lake 10 feet, there has been an increased harvest of pike as well as walleye and a considerable decrease in the harvest of whitefish (Fig. 3.2).

Until 1962 whitefish were the most important species commercially but with mercury closure in 1971, walleye and pike had become the dominant commercial species. This is consistent with other reservoir data available. If Lac Seul (Crooks, MS 1972) can be used as an example production will continue to rise for a number of years, particularly for pike and walleye, but will eventually decrease to a level somewhat lower than existed prior to flooding.

Split Lake

Since 1954 the fishery has been entirely a summer operation wit an average yield of 322.6 cwt consisting primarily of whitefish (Fig. There is also a 250 cwt annual domestic fishery (Schlick, MS 1968) whi would give Split Lake an average annual fish yield for the past ten yea of 0.82 pounds per acre. In 1971 the walleye and pike fishery was clos due to mercury and since this time the commercial fishery has been entirely for whitefish.

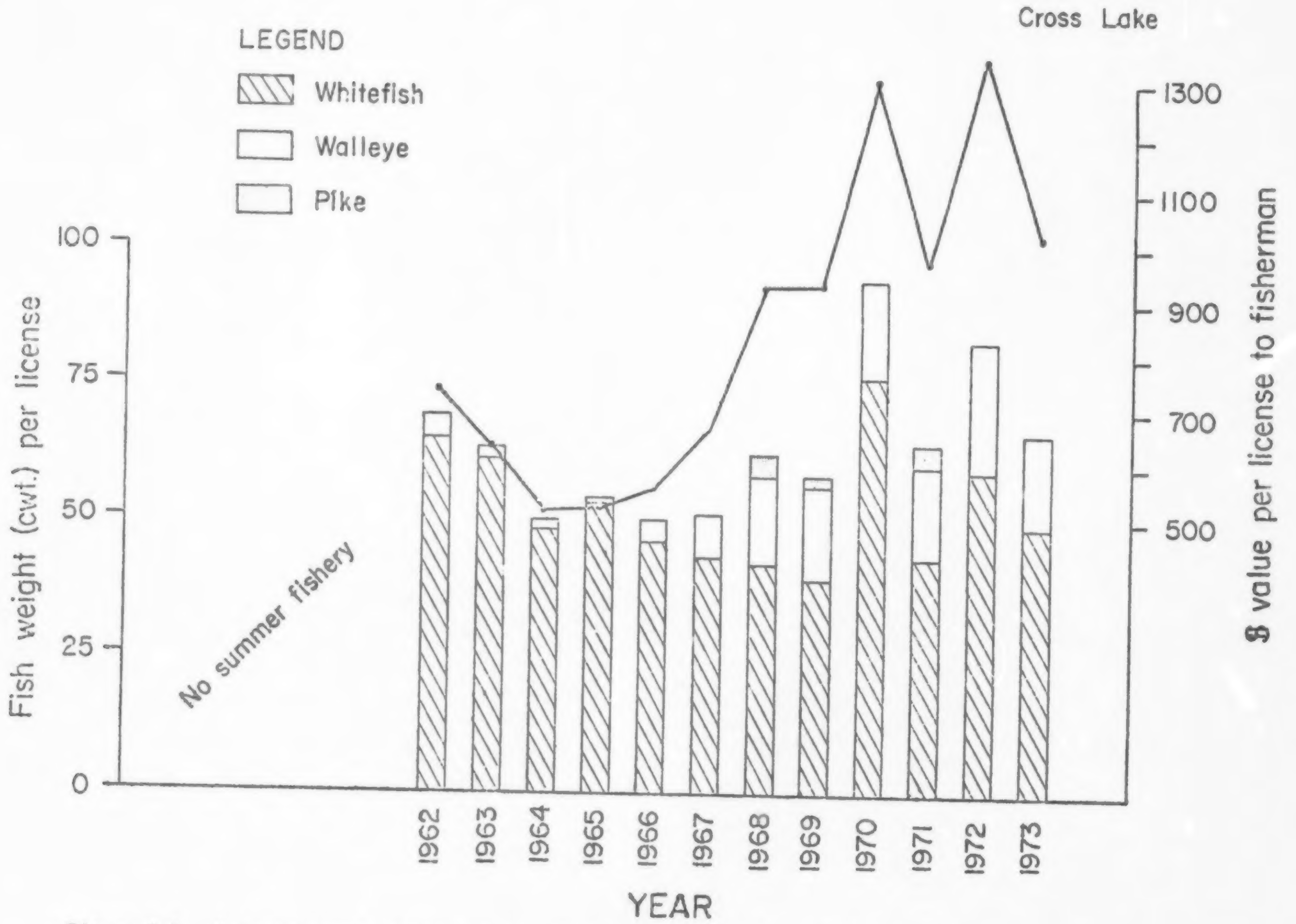

Figure 3.1. Average pounds taken per license and average value per license of the summer commercial catch on Cross Lake.

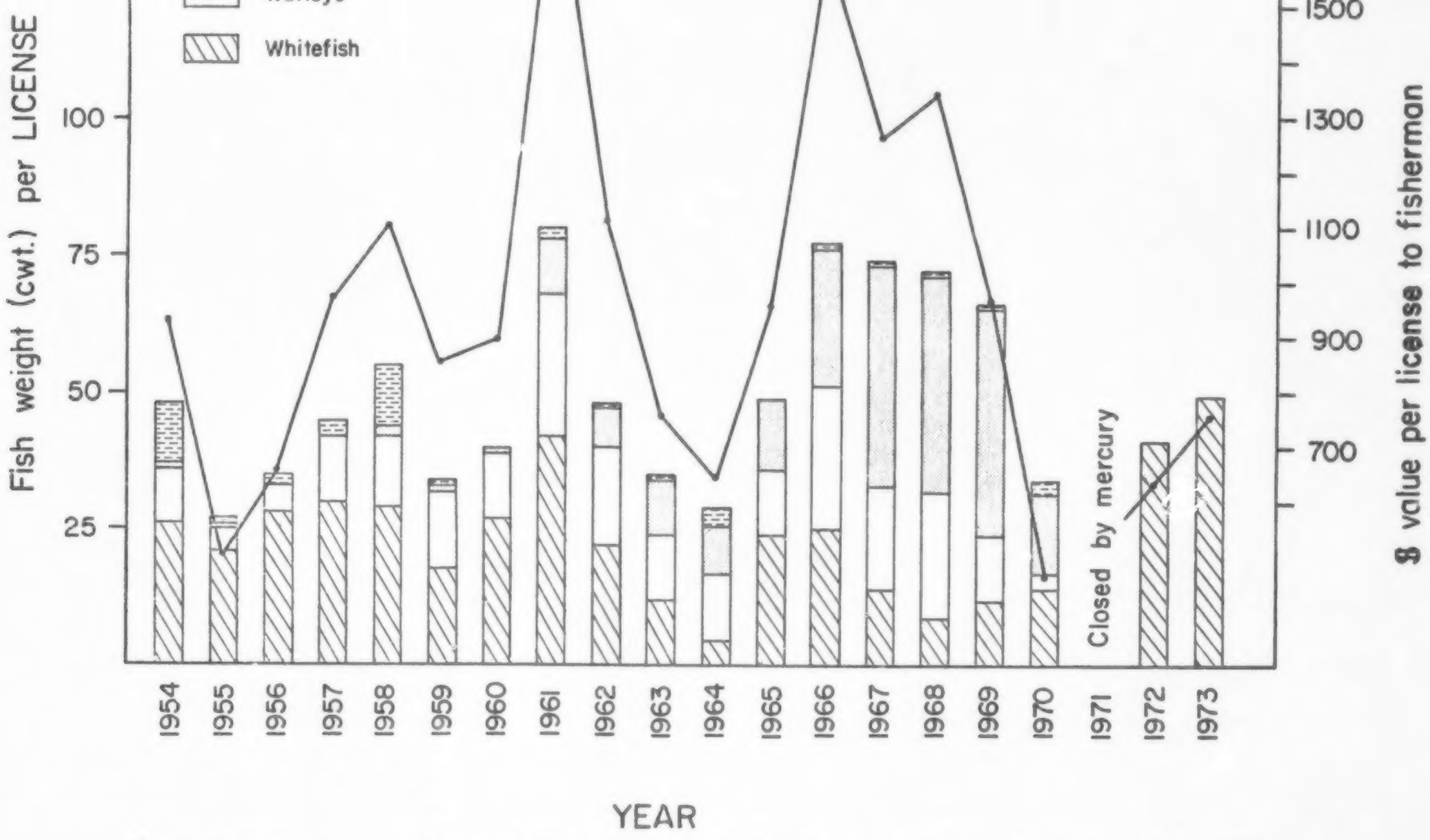

Figure 3.2. Average pounds taken per license and average value per license of the summer commercial catch on Sipiwesk Lake.

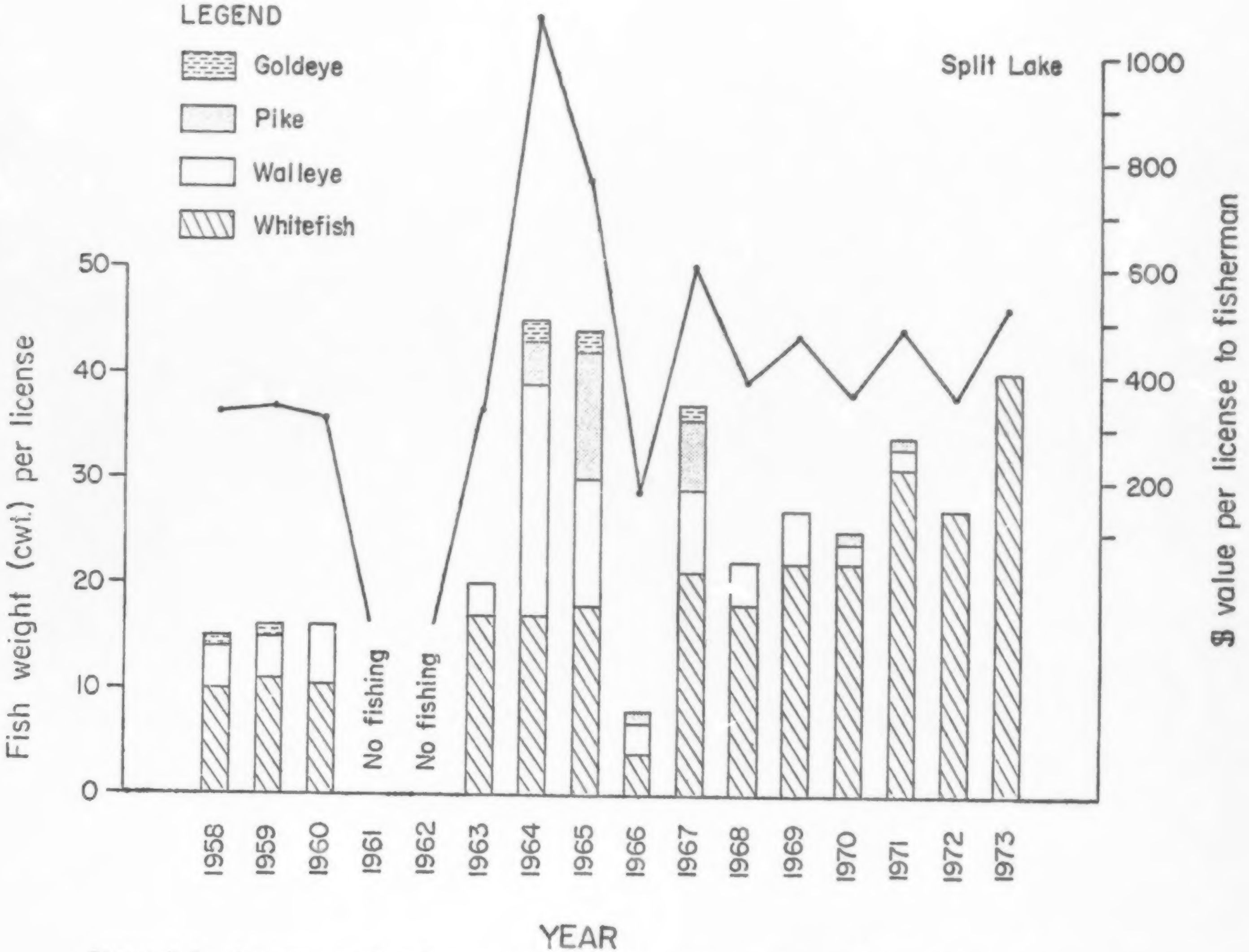

Figure 3.3. Average pounds taken per license and average value per license of the summer commercial catch on Split Lake.

3.5. FISH PRODUCTION

Comparative fish production data for similar mesh sizes previous provincial government studies have been outlined in Ta However, since all provincial government survey sets are known overnight sets production figures could differ somewhat due to in set duration for provincial surveys when compared to fisher duration.

Relative numbers of fish for Cross Lake in 1973 are gre those reported by Driver and Doan (MS 1972). All species exce and burbot are numerous. However, the mean weight of the fis is lower for the fisheries survey. This results in a similar production in pounds.

In Sipiwesk Lake fish production has generally doubled Schlick's (MS 1968) survey. This increase is likely due in pa increased pike and walleye production in the new reservoir. H commercial production was also considerably decreased that yea be related to over-exploitation in 1963 when Schlick (MS 1968) illegal nets were involved. Furthermore some of this increase be due to decreased fishing pressure in the last few years wh licenses were issued and some species were closed due to mercu weights appear to be slightly lower for whitefish and higher f Otherwise, mean weights appear to be similar to the previous s

Split Lake had a 70% increase in walleye and whitefish The walleye production might be linked somewhat to decreased f pressure due to mercury closure but it is difficult to explain t increase in whitefish production as well as the apparent decreas production of all other species.

Table 3.3 outlines fish production, mean weight, and mea length for the same mesh sizes and duration of net night (16 hou used on Southern Indian Lake in 1973.

Kettle Reservoir has a very poor production of commercia important species when compared to the other lakes studied. Pro consists primarily of whitefish with walleye and cisco being of importance. This low production is not unexpected since Kettle only been flooded for 3 years, it was previously a river channel it is essentially a new population of each species.

Moose Lake, which is part of the Kettle complex, is isol a narrow creek and although levels have been increased, there ap be little water exchange with the mainstream Nelson River. Ther extremely abundant whitefish and cisco production secondary only Lake. These populations probably represent unexploited populati the lakes prior to flooding since there is no commercial fishery

Overall fish production for similar species from Souther Lake (Ayles and Koshinsky, MS 1974) was 152 pounds per net night the Lower Churchill River lakes (see section 1) from 155 to 175 per net night. Thus, Cross Lake is more than twice as productiv Churchill River lakes while Moose is roughly comparable and Spli Sipiwesk Lakes are approximately 30% less. Kettle Reservoir is mately 70% less productive than the lower Churchill River lakes Southern Indian Lake.

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Table 3.2. Comparative catch per unit effort[1] and mean weights for fish species fro Nelson River Lakes.

I. Catch per unit effort.

SPECIES	CROSS		SIPIWESK		SPLIT		K
	A	B	A	C	A	D	A
whitefish	22.8	14.5	6.3	1.5	17.8	9.2	14
walleye	27.2	38.3	10.6	3.1	16.8	8.7	4
pike	24.2	19.5	6.3	3.9	1.0	3.0	
cisco	50.8	47.2	4.8	3.3	0.8	7.5	8
sauger	1.4	-	1.3	0.9	2.2	1.3	0
goldeye	16.4	-	14.0	4.0	0.2	17.3	
perch	-	0.5	0.1	-	-	-	
white sucker	16.5	8.5	25.8	32.0	19.4	20.7	3
longnose sucker	0.2	-	0.1	-	2.5	0.2	29
redhorse sucker	1.6	-	3.4	-	0.3	-	0
burbot	0.4	1.0	-	-	0.2	-	0
freshwater drum	-	-	0.2	-	-	-	
Total	161.5	129.5	72.9	48.7	61.2	67.9	61

II. Mean weights.

SPECIES	CROSS A	CROSS B	SIPIWESK A	SIPIWESK C	SPLIT A	SPLIT D	K A
whitefish	2.5	3.0	2.1	2.8	1.6	1.8	0
walleye	2.0	2.0	1.4	1.5	1.9	2.0	1
pike	2.5	2.9	4.8	5.1	6.9	3.5	
cisco	1.3	1.5	1.0	1.2	0.8	0.8	0
sauger	1.1	1.6	0.8	0.6	0.8	0.7	1
goldeye	0.9	-	1.0	0.5	0.6	0.6	

[1] Catch per unit effort was not adjusted to 16 hours. Since Schlick and Driver a overnight sets without any adjustment it is felt that by not converting fisheri more representative comparison is facilitated.

A Fisheries survey 1973.

B Driver and Doan MS 1972.

C Schlick MS 1968a.

D Schlick MS 1968 b.

* Denotes only 1 fish in that sample.

Table 3.3. Catch per unit effort, mean weights and mean lengths of six fish species from fisheries net sizes for the Nelson River lakes.

I. Catch per unit effort (pounds)

Species	Cross	Sipiwesk	Split	Kettle	Moose
whitefish	62.6	18.3	43.7	18.0	100.0
walleye	95.8	25.5	35.5	8.5	1.2*
pike	108.8	36.6	11.2	2.8	17.4
cisco	138.5	9.0	4.2	9.1	44.7
sauger	3.3	0.5	6.1	0.6	-
goldeye	18.5	16.7	6.3	0.1*	-
TOTAL	427.5	106.6	107.0	39.1	163.3
II. Mean weight (pounds)					
whitefish	1.96	1.60	0.94	0.52	2.40
walleye	1.57	0.87	0.82	0.85	2.25*
pike	2.50	3.78	2.86	0.80	1.80
cisco	0.83	0.80	0.41	0.31	1.00
sauger	0.94	0.40	0.44	0.55	-
goldeye	0.84	0.40	0.77	0.50*	-
III. Mean lengths (inches)					
whitefish	14.4	13.1	10.3	9.7	14.6
walleye	15.8	11.9	12.1	11.8	17.8*
pike	21.2	22.9	20.1	16.4	18.0
cisco	10.0	10.4	8.1	7.4	10.7
sauger	13.2	9.4	11.1	11.5	-
goldeye	11.1	9.4	10.3	9.2*	-

* denotes only 1 fish in that sample.

3.6. WHITEFISH

Weighted mean fork lengths-at-age (Table 3.4) were prepared from back-calculated data. From this data Cross Lake and Kettle Reservoir appeared to have the best growth rates, while Split Lake had the slowest. Generally the Nelson River lakes appeared to have a slightly better growth rate than those for whitefish in the lower Churchill River lakes and Southern Indian Lake (see section 1). From Table 3.5 it appears that whitefish from the lower Nelson River lakes had significantly slower growth rates than the whitefish from Lake Winnipeg and the outlet lakes. However, aging of the fish scales were completed by different people for the two sets of data and descrepancies could result in this manner.

Whitefish condition regression formulae are outlined below:

Cross	$\log W = -5.55 + 3.31 \log FL$
Sipiwesk	$\log W = -5.66 + 3.35 \log FL$
Split	$\log W = -4.78 + 3.01 \log FL$

(logs to base 10, fork length in mm, and weight in grams).

Statistical analysis of slopes and elevations of these regression lines indicate that Moose Lake whitefish were in better condition (plumper at a given length) than whitefish from the other lakes. Overall, whitefish condition was similar to whitefish condition in the lower Churchill River system (section 1) and in the outlet lakes region (Ayles,MS 1973).

Whitefish food has been summerized in Table 3.6. Whitefish in these areas fed almost exclusively on various benthic organisms. These organisms have been listed as preferred species by other authors such as McPhail and Lindsey (1970) and Scott and Crossman (1973). The diet of Nelson River lake whitefish was similar to that of whitefish in the lower Churchill River lakes. There was, however, very limited usage of amphipods as reported by Ayles and Koshinsky (MS 1974) for Southern Indian Lake.

Experimental gillnet catches (Table 3.3) suggest that Moose Lake was the most productive whitefish lake. However, net sets were limited (2) and perhaps these figures are misleading. Cross Lake was the most productive being roughly comparable to Southern Indian Lake (57.7 lbs. - Ayles and Koshinsky, 1974) but lower than the lower Churchill River lakes (75.9 lbs - section 1). Split Lake also had a fairly good fish production, however, Kettle and Sipiwesk lakes production was 71% lower than Cross Lake production. According to experimental gillnet studies in 1973 whitefish production has increased 57% in Cross Lake, 94% in Split Lake, and 320 % in Sipiwesk Lake from earlier provincial government surveys (Table 3.2.).

Table 3.4 Average weighted fork length (mm) at each annulus for whitefish from the upper Nelson River lakes.

	1	2	3	4	5	6	7	8	9	10
Cross Lake										
Average Fork Length	104	178	244	301	347	583	401	454	502	
Increment	104	74	66	57	46	36	18	53	48	
Number	56	55	52	46	43	33	11	2	1	
Sipiwesk Lake										
Average Fork Length	100	157	214	266	312	347	368	381	323	
Increment	100	57	57	52	46	35	21	13	-	
Number	56	56	54	52	42	32	27	8	1	
Split Lake										
Average Fork Length	82	149	205	245	285	321	354	385	407	417
Increment	82	67	56	40	40	36	33	31	22	10
Number	49	44	41	39	33	25	17	7	4	2
Kettle Reservoir										
Average Fork Length	122	185	214	284	333					
Increment	122	63	56	43	49					
Number	42	42	37	11	3					
Moose Lake										
Average Fork Length	98	168	222	257	309	338	371	390	414	
Increment	98	70	54	35	52	29	33	19	24	
Number	7	7	7	6	6	5	5	3	2	

Table 3.5. Comparative length-at-age data for whitefish, pike, and walleye for the upper Nelson River lakes and in the Lake Winnipeg outlet lakes[1] (fork length in inches).

Whitefish	1	2	3	4	5	6	7	8	9	10
Cross	4.1	7.0	9.6	11.9	13.7	15.1	15.8	17.9	19.8	-
Sipiwesk	-	6.2	8.4	10.5	12.3	13.7	14.5	15.0	-	-
Split	3.2	5.9	8.1	9.7	11.2	12.6	13.9	15.2	16.0	16.4
Kettle	-	7.3	9.5	11.2	13.1	-	-	-	-	-
Moose	-	-	8.7	10.1	12.2	13.3	14.6	15.4	16.3	-
Lake Winnipeg	-	-	13.0	15.4	16.0	18.1	-	-	-	-
Playgreen	-	10.1	11.5	14.2	15.6	16.4	17.3	-	-	-
Kiskittogisu	-	10.4	11.8	13.5	15.2	16.2	17.2	18.4	18.1	-
Kiskitto	-	10.5	10.9	13.7	14.6	16.1	17.2	17.7	18.2	-
Cross	-	9.0	11.9	13.0	16.1	16.3	18.1	19.8	21.2	21.8

Walleye	1	2	3	4	5	6	7	8	9	10
Cross	5.4	7.5	9.8	12.1	13.8	15.3	15.7	16.3	17.5	-
Sipiwesk	4.8	6.7	8.7	10.4	11.9	13.5	14.5	14.5	-	-
Split	5.4	7.4	9.4	11.3	12.9	13.8	14.7	17.6	-	-
Kettle	-	7.2	9.4	11.6	13.4	14.8	16.0	17.8	-	-
Playgreen	-	12.3	13.3	14.7	16.0	18.1	17.5	21.0	-	-
Kiskittogisu	-	-	13.2	15.0	16.3	17.8	18.9	-	-	-
Kiskitto	-	11.5	12.5	13.9	15.3	16.5	19.3	17.5	-	-
Cross	-	-	13.1	13.2	16.0	17.5	18.6	19.0	21.4	21.2

Pike	1	2	3	4	5	6	7	8	9	10	11
Cross	-	10.9	14.3	17.0	18.9	20.4	21.7	22.7	25.8	-	-
Sipiwesk	-	-	12.4	15.4	18.0	19.8	21.5	22.9	24.8	26.1	28.0
Split	-	-	12.7	15.1	16.9	18.9	20.2	21.9	23.1	26.9	28.9
Kettle	-	9.2	12.6	17.0	19.5	20.0	-	-	-	-	-
Moose	-	10.0	13.0	16.1	18.2	19.8	22.4	-	-	-	-
Playgreen	9.5	-	16.7	18.4	20.4	22.5	24.2	25.7	26.3	-	-
Kiskittogisu	-	-	16.3	18.1	20.4	22.7	26.6	28.2	29.7	-	-

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[1] After Koshinsky MS 1973.

Table 3.6. Percent food by weight for whitefish from the upper Nelson River Lakes.

Food	Sipiwesk Lake	Cross Lake	Split Lake	Kettle[1] Reservoir
Ephemeroptera	26.8	70.1	1.7	
Sphaeridum	20.9	9.6	76.5	0.1
Valvata	3.8	2.5	9.5	< 0.1
Trichoptera	0.9	1.8	< 0.1	< 0.1
Chironomidae	0.4	0.6		0.2
Corixidae	0.1	< 0.1		2.2
Gastropoda	47.0	10.8	12.3	< 0.1
Copepoda				0.1
Ostracoda		0.1		97.4
Amphipoda		1.4		
Hirudinae		1.0		
Plecoptera		2.1		
No examined	73	139	200	196

[1] Includes Moose Lake.

3.7. WALLEYE

According to back-calculated data (Table 3.7) it appeared that Split, Kettle, and Cross Lakes had similar growth rates for walleye while Sipiwesk Lake walleye appeared to have a slower growth rate. A comparison of length-at-age data of the lower Nelson River lakes and Lake Winnipeg outlet lakes (Table 3.5) suggests that the lower Nelson River lakes had a slower rate of growth than the outlet lakes. Growth rates appeared to be comparable if not slightly better than the lower Churchill River lakes (section 1).

Condition regression formulae for walleye are as follows:

Cross $\log W = -5.44 + 3.2 \log FL$

Sipiwesk $\log W = -5.20 + 3.1 \log FL$

Split $\log W = -5.36 + 3.2 \log FL$

Kettle $\log W = -5.61 + 3.3 \log FL$

(logs to base 10, fork length in mm, and weight in grams).

Statistical comparisons of slopes and elevations of these regression formulae indicate that there was no significant difference in condition between walleye from Cross, Sipiwesk, and Kettle Lakes. However, Split Lake walleye were in significantly superior condition (plumper at a given length). Condition of walleye in the Nelson River lakes appeared to be better than for walleye in the lower Churchill River system (section 1).

The diet of walleye (Table 3.8) was generally similar to that described for walleye from Southern Indian Lake (Ayles and Koshinsky, MS 1974) with the following exceptions. Ephemeroptera were important walleye from Sipiwesk Lake and crayfish were the major food item of walleye in Split Lake. This abundance of crayfish is unusual and suggests that there may be a lack of more preferable items (fish and insects) or a greater relative abundance and accessability of crayfish in this lake when compared to others.

Cross Lake was the most productive lake for walleye (Table 3.3) and both Cross and Split Lakes had greater walleye production than was recorded from Southern Indian Lake (23.3 lbs., after Ayles and Koshins MS 1974). Compared to provincial government data (Table 3.2) producti of walleye has decreased in Cross Lake (-29%) from the 1965 survey. Production has increased 2-3 times in Split and Sipiwesk Lakes since t 1966 surveys which is likely related, in part, to the reduced fishing pressure after the closure of the fishery to walleye.

Table 3.7. Average weighted fork length at each annulus for walleye from the upper Nelson River Lakes.

	1	2	3	4	5	6	7	8	9	10
Split Lake										
Average Fork Length	137	188	238	288	327	351	374	446		
Increments	137	51	50	50	39	24	23	72		
Number	50	48	44	32	27	18	8	1		
Sipiwesk Lake										
Average Fork Length	123	171	220	263	303	343	368	367		
Increments	123	48	49	43	40	40	25	-		
Number	48	44	36	34	27	20	11	5		
Cross Lake										
Average Fork Length	136	190	250	306	350	389	399	415	444	
Increments	136	54	60	56	44	39	10	16	29	
Number	58	56	52	49	43	29	11	1	1	
Kettle Reservoir										
Average Fork Length	120	184	238	294	339	377	406	453		
Increments	120	64	54	56	45	38	29	47		
Number	48	48	38	24	12	7	5	1		

Table 3.8. Percent food by weight for walleye from the upper Nelson River Lakes.

FOOD	Sipiwesk Lake	Cross Lake	Split Lake	Kettle Reservoir
Perch	0.4	0.8	0.3	
Trout-Perch			0.5	
Cisco	5.2	24.5	0.8	
Northern Pike	2.8	17.2		
Burbot	5.6			
Whitefish			6.7	
Fathead Minnow		0.2		
Cisco/whitefish		10.8		
Spottail Shiner		0.1		
9-spine Stickleback				13.7
Lake Chub				16.3
Unidentified Fish Remains	48.4	32.2	20.8	70.1
Ephemeroptera	33.9	0.5	0.1	
Mysidacea	1.0			
Hirudinae	0.6	0.2		
Crayfish	0.5		70.7	
Trichoptera	0.2	< 0.1		
Amphipoda	0.1	< 0.1		
Chironomidae		< 0.1		< 0.1
Sphaeridae			0.1	
No Examined	217	295	219	35

3.8. NORTHERN PIKE

The discussion on northern pike from Kettle Reservoir is limite to the pike taken in deep water samples only. Pike were plentiful in near shore areas (according to local anglers) but submerged vegetation along the flooded shorelines prevented the successful use of gillnets.

Pike sampled from the Kettle Reservoir appeared to have a rapid rate of growth which is comparable to young pike from Cross Lake (Table 3.9). This is not unexpected in a new reservoir and excellent growth of pike will likely continue for a number of years. Pike from Split Lake had a very slow rate of growth which is likely a reflection of the food taken in this lake.

Comparative length-at-age data indicated that the Nelson River Lakes pike of this study had a significantly slower growth rate than the pike from the Lake Winnipeg outlet lakes (see Table 3.5). The lower Churchill River Lakes also appeared to have a more rapid growth rate (section 1).

Condition regressions for the Nelson River lakes pike were as follows:

Cross $\log W = -4.13 + 2.63 \log FL$
Sipiwesk $\log W = -4.69 + 2.84 \log FL$
Split $\log W = -5.75 + 3.22 \log FL$
Kettle $\log W = -4.92 + 2.92 \log FL$
Moose $\log W = -4.93 + 2.94 \log FL$

(logs to base 10, fork length in mm, and weight in grams).

Statistical comparisons of slopes and elevation of these fo generally indicate that there were no significant differences from regression line for condition of pike from Split, Kettle, Sipiwesk Moose Lakes while Cross Lake pike were in significantly poorer con Overall pike condition appeared to be better than in Southern Indi Lake (Ayles and Koshinsky, MS 1974) where the condition regression formula was:

$$\text{Log } W = -6.71 + 2.6 \ \log FL$$

However, condition of pike from the Nelson River lakes was poorer the condition of pike from the lower Churchill River system (secti

Pike in these lakes appear to feed primarily on fish (Table however, crayfish also are an important dietary constituent.

The highest production for pike was in Cross Lake (Table 3. where they comprised 25% of the commercially important species. Lake also has a good pike production. The other lakes were quite (in particular Kettle Reservoir). Pike production appears to have in Sipiwesk and Cross Lakes and decreased in Split Lake since pro surveys in 1965 and 1966 (Table 3.2). Catch per unit effort (lbs) for Southern Indian Lake is 43.3 (Ayles and Koshinsky, MS 1974) an averages 76.1 (section 1) for the lower Churchill River lakes. C Lake is the only Nelson River lake more productive than these, al the production in Sipiwesk approaches that of Southern Indian Lak

Table 3.9. Average, weighted, fork length at each annulus for Northern pike from the upper Nelson River lakes. (Fork length in mm)

	1	2	3	4	5	6	7	8	9	10	11	12	13
Cross Lake													
Average Fork Length	172	276	362	431	479	517	550	576	654				
Increments	172	104	96	69	48	38	43	26	78				
Number	50	50	49	48	41	30	16	7	1				
Sipiwesk Lake													
Average Fork Length	158	228	315	390	456	503	545	581	631	662	712		
Increments	158	70	87	75	66	47	42	36	40	31	50		
Number	46	46	46	43	41	36	29	23	13	6	3		
Split Lake													
Average Fork Length	173	255	322	384	429	480	514	557	587	682	733	803	847
Increments	173	82	67	62	45	51	34	43	30	95	41	70	44
Number	18	18	18	15	14	12	10	9	6	3	3	2	2
Kettle Reservoir													
Average Fork Length	155	234	321	432	496	508							
Increments	155	79	87	111	64	12							
Number	20	20	15	4	2	1							
Moose Lake													
Average Fork Length	173	255	331	409	962	503	568						
Increment	173	82	76	78	53	41	65						
Number	24	24	22	19	9	6	5						

Table 3.10. Percent food by weight of northern pike fr
Nelson River Lakes.

Food	Sipiwesk Lake	Cross Lake	Split Lake
Burbot	25.6	0.4	
Walleye	2.5	3.4	
Trout-perch	0.4		
Sculpin	0.7		
Crayfish	32.7	19.5	100.0
Ephemeroptera	< 0.1	0.1	
Plecoptera	0.1		
Goldeye	16.1		
Sauger	25.8		
Unid. Fish Remains	9.2	5.2	
Cisco		38.6	
Perch		0.1	
Cisco/Whitefish		5.3	
Whitefish		6.9	
White Sucker		8.3	
Northern Pike		9.4	
Spottail Shiner		0.9	
Lake Chub		1.6	
9-spine Stickleback			
Longnose Sucker			
Hirudinae	< 0.1	0.2	
Chironomidae		< 0.1	
Sphaeridae		< 0.1	
Amphipoda		< 0.1	
No examined	72	261	7

1 includes Moose Lake.

3.9. CISCO

From field observations of size at maturity there appears to be more than one species of cisco involved in these lakes. However, no differentiation was made.

Cisco were the most abundant species in Cross Lake comprising 32% of the production. They ranked second in numbers and production in Moose Lake. From stomach analysis cisco were the most important prey species for pike in these lakes making up 39% and 57%, respectively, of the diet. Overall cisco abundance was low in the other lakes studied (Table 3.3).

Regression analysis for condition was performed; however, a significant amount of variability was encountered, perhaps supporting the theory of more than one species.

Generally benthos contributed upwards of 85% of cisco diet except in Moose Lake and Kettle Reservoir where pelagic organisms (cladocera) made up a significant portion (27%) of the diet. No Mysis or fish were found as was the case for cisco in Southern Indian Lake (Ayles and Koshinsky, MS 1974).

3.10. GOLDEYE

Goldeye are a commercially valuable species and have been marketed from Split and Sipiwesk Lakes. This is the most numerous species in Sipiwesk Lake (15% of the catch by weight), although, the catch-per-unit effort (Table 3.3) was highest in Cross Lake. According to McPhail and Lindsey (1970) goldeye are adaptable to turbid conditions. Therefore, it is not unreasonable that this species does well in the Nelson River system.

In Cross and Sipiwesk Lakes, which were fished in early summer (June and early July), goldege were taken in large numbers from only one or two sets. Whereas in later summer the distribution throughout Split Lake appeared to be quite random.

The diet of goldeye in this study consisted primarily of benthos (Ephemeroptera, >83% in all cases). Although Kennedy and Sprules (1967) list this as a likely food source, Scott and Crossman (1973) report that goldeye feed extensively in surface waters in summer. Some hemipterans and coleopterans were found in stomach analysis.

Goldeye were not used extensively as a prey species by pike and walleye in the Nelson River lakes.

3.11. WHITE SUCKER

The common sucker is present in all the lakes studied on the Nelson River system. According to experimental gillnet sets they are the most abundant species in Sipiwesk and Split Lakes (Table 3.2).

The mean lengths for the suckers caught are as follows; Cross 15.9 in., Sipiwesk 15.6 in., Split 14.8 in., Kettle 12.1 in., and Moose 15.3 in. In all cases except Kettle Reservoir, which is a young population, these mean lengths are greater than the 13.9 in. recorded by Ayles and Koshinsky (1974) for Southern Indian Lake.

The species has no commercial importance in this area and appears to serve as a major forage species for walleye and pike only in Cross Lake. Suckers are, however, major competitors with whitefish and cisco for benthos stocks.

3.12. LONGNOSE SUCKER

This species was caught in appreciable numbers only in Kettle Reservoir where they make up the bulk of the fish production. In Split Lake the composite catch per unit effort (non-adjusted) was 7.7 fish whereas in Kettle composite catch per unit effort (non-adjusted) was 103.7 fish.

According to Scott and Crosman (1973) longnose suckers prefer deep, clear, cold lakes. Since Kettle is a deep,turbid, isothermal , system (Crowe,MS 1972), one would not expect such an abundant population. However, Crowe (MS 1972) reports many streams running into the region which could serve as possible spawning sites.

The mean length was 12.1 inches in Kettle and 13.0 inches in Split Lake. Three major peaks were evident from length-frequency data in Kettle (7.5 inches, 11 inches, and 14 inches). These probably represent the first 3 year classes.

Longnose suckers were also the most important forage species for pike in Kettle, making up 31% of the diet.

3.13. BURBOT

Generally, burbot were not plentiful throughout the system. The greatest number were captured from Kettle Reservoir and Split Lake. This species prefers deep waters and the cool hypolimnion in summers (Scott and Crossman, 1973). The isothermal lakes of the Nelson River system would not be a prefered habitat and it is surprising that a fair number of young burbot were captured from the spot poisons especially in Kettle Reservoir and Split Lake.

In all the upper Nelson River Lakes burbot diet consisted primarily of crayfish with fish being of secondary importance. Scott and Crossman (1973) report burbot up to 12 inches feed upon invertebrates such as amphipods, ephemeroptera, and crayfish but after 19 inches feed exclusively on fish. The mean length of burbot from Kettle was 11.5 inches and from Split Lake was 14.7 inches.

3.14. SAUGER

Difficulty in identification of this species was encountered in some of the Nelson River Lakes especially in the more immature specimens. A hybrid with walleye may be involved. Scott and Crossman (1973) report this possibility for more southernly lakes.

Sauger were not numerous in the upper Nelson system and the species is probably reaching the northern limits of its range in this region. The species does not make up a significant portion of the commercial catch. The mean lengths and weights (Table 3.3) are consistent with values found by Ayles and Koshinsky (MS 1974) for Southern Indian Lake.

The diet of sauger in these lakes was almost exclusively fish although some ephemeroptera larva were found in stomachs from Sipiwesk Lake.

3.15. OTHER FISH SPECIES

There were very few perch caught in the upper Nelson River lakes; the greatest number being caught in Cross Lake (10). Perch do not tolerate elevated turbidities and flows (Scott and Crossman, 1973). The Nelson lakes are turbid and have strong currents, and therefore are quite unsuitable for perch.

A few shorthead redhorse suckers were caught, primarily in Sipiwesk and Cross Lakes. This species has a relatively wide distribution in Canada but a low abundance. Redhorse suckers are not tolerant to silt and debris and therefore, probably not well suited to the Nelson River lakes.

Lake chub were found in the stomachs of pike and walleye in Cross Lake and Kettle Reservoir as well as being in small numbers in the smaller meshes of the experimental gillnets. Lake chub have an extremely wide distribution in Canada (Scott and Crossman, 1973) and are highly adaptable to living in rivers or lakes.

3.16. IMPLICATION OF REGULATION AND DIVERSION

The immediate effects of Lake Winnipeg regulation on Cross Lake have been discussed by Koshinsky (MS 1973). Sipiwesk Lake will underg a similar reversal of the water regime and greater month-to-month fluctuations. However, the levels should be within present regulated conditions and with control at Kelsey it is difficult to estimate any potential negative effects on the present system.

Split Lake will suffer the major impact on the Nelson River. Wi an increased flow of almost 30,000 cfs from the Odei-Burntwood system and since the majority of the Churchill River diversion route has a lacustrine clay overburden, a potentially severe silting and turbidity problem will arise. Furthermore, although Manitoba Hydro is developing a system of booms along the diversion route for debris control, submerged and floating debris may present a problem for travel and gillnet fishing. The increased flows will also increase levels but to what extent is unknown at present.

The silting effect could result in decreased benthos populations and therefore, reduced food supplies for fish such as whitefish, cisco, and walleye which also appear to be utilizing benthos material in this lake. Also, silting could have a negative effect on deposited spawn of lake spawners such as whitefish and cisco as well as any lake spawning populations of walleye and pike.

Higher turbidity will decrease primary productivity and as a result have a negative effect on all trophic levels. Moreover, greater turbidities will have an adverse effect on sight feeding young of such species as cisco, walleye, and whitefish.

Kettle Reservoir is essentially a new "lake" and the species of fish which have become established in the past 3 years will continue to benefit from the new reservoir for a number of years. However, the exchange time in this reservoir is low and with the addition of the Churchill River flow there will be even a further increase in flushing rates. Following shoreline stabilization the production of this reservoir will peak and then decrease, stabilizing at some lower level.

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APPENDIX 5 -

THE FISHERIES OF THE
RIVER AND DIVERSIO
EXPLOITATION AND

THE FISHERIES OF THE LOWER CHURCHILL RIVER AND DIVERSION ROUTE LAKES: EXPLOITATION AND REPRODUCTION

by

K. V. WEAGLE
Fisheries and Marine Service
Environment Canada
Winnipeg, Manitoba
March, 1974

for

THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

SPECIAL NOTE

THE CONCLUSIONS AND RECOMMENDATIONS CONTAINED IN THIS APPENDIX ARE THOSE OF THE AUTHOR(S) AND ARE NOT NECESSARILY THE SAME AS THE CONCLUSIONS AND RECOMMENDATIONS OF THE LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD AS EXPRESSED IN THE SUMMARY REPORT AND THE TECHNICAL REPORT.

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SUMMARY

a) The commercial fishery on the lower Churchill River lakes is presently safe from over-exploitation and has in recent years approached the production quota.

b) The lower lake levels of the lower Churchill River lakes and the chance of reduced fishing effort in the area will result in a 60 to 75% reduction in commercial fish production after diversion.

c) Mitigation measures to be considered for the above lakes are fixed crest weirs at their outlets to maintain present water levels and a compensation program to assist fishermen who experience a reduction in income because of the program.

d) The commercial fishery on the diversion route lakes appears to be very underfished and produces approximately 30% of the quota.

e) The increased water levels in the area causing extensive areas of flooded timber and inundating fish camps will cause a 90 to 100% reduction in the commercial production of this area.

f) Mitigation measures for the area should include compensation for the fishermen who suffer reduction in income and for the owners of fish camps that are inundated.

g) The sport fishing potential of the lower Churchill River will decrease after diversion and the sport fishing potential of the diversion route will increase because of the "tail-race" fishery at Notigi and increased pike habitat.

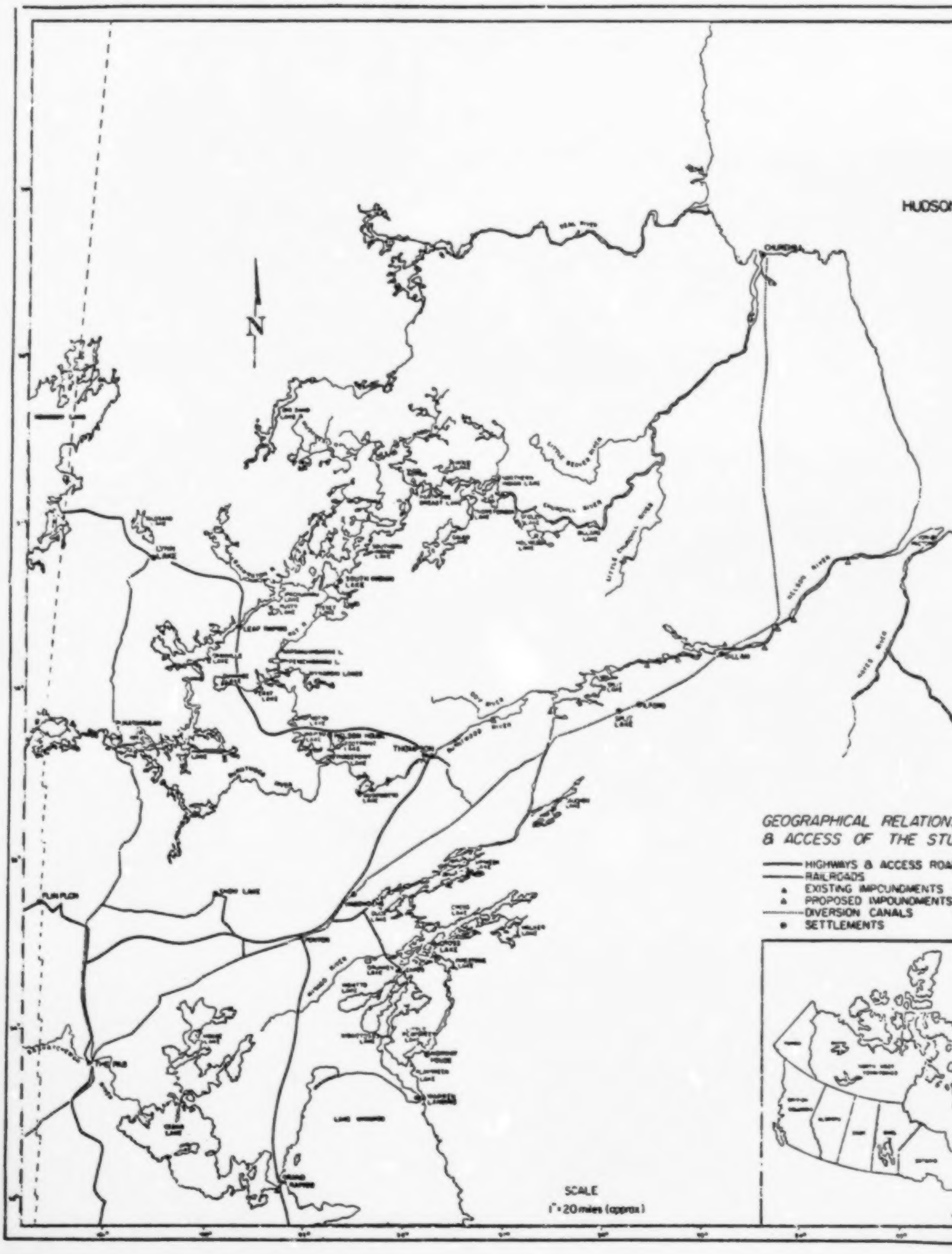
h) The clearing of the Suwannee River area would be a useful mitigation measure to help maintain the walleye populations in the Notigi reservoir.

1. INTRODUCTION

This report will describe the past and present state of the commercial fisheries on the lakes along the diversion route from South Bay, Southern Indian Lake to Split Lake on the Nelson River. These include Pemichigamau, Rat, Notigi, Wapisu, Mynarski and Wuskwatim Lakes. It will also report on the past and present states of the lakes on the lower Churchill River, downstream of Southern Indian Lake. These include Partridge Breast, Northern Indian, Fidler and Billard Lakes (Figure 1).

The small commercial fisheries in these areas put them low on the priority list of the Fisheries, Limnology Task and no field work to expand on the commercial fishery was conducted on any of these lakes. This report shall, therefore, merely summarize the data found with regard to the commercial fisheries and predict the impact of the diversion on these fisheries.

The report also contains brief mention of the impact of the diversion on the sport fishery in these areas and on fish reproduction.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HIGHWAYS & ACCESS ROA
RAILROADS
EXISTING IMPOUNDMENTS
PROPOSED IMPOUNDMENTS
DIVERSION CANALS
SETTLEMENTS
SCALE
1" = 20 miles (approx)

FIGURE 1. Northern Manitoba showing the location of lakes mentior

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2. THE LOWER CHURCHILL LAKES

2-1 Partridge Breast Lake:

The first records of a commercial fishery on Partridge Breast Lake are from the 1965-66 winter season when 700 lbs of fish valued at $82 were taken. The summer seasons began in 19 with 18,200 lbs of fish valued at $1,820 being taken by 8 fish men (Figure 2). The fishery was pursued until 1969 but no rec have been found for 1969 to the present. The quota of 20,000 of whitefish, walleye and trout has never been reached. The average yield-per-acre on the lake is 0.9601 lbs of which 96% are whitefish and 4% are pike (Wickstrom and Merner, 1970).

At present fish produced on Partridge Breast Lake woul be flown to one of the fish camps on Southern Indian and from there to Leaf Rapids, Lynn Lake and Winnipeg.

The value of the fishery has varied from $372 in 1967 $3,461 in 1969.

2-2 Northern Indian Lake:

Northern Indian Lake is the largest lake on the lower Churchill system and has a quota of 90,000 lbs of whitefish, w eye and lake trout. The fishery began during the 1948-49 wint season and continued until the 1967-68 winter season and was a fished during the 1969-70 winter season (Figure 3). The summe season began in 1968 and has continued until the present (Figu

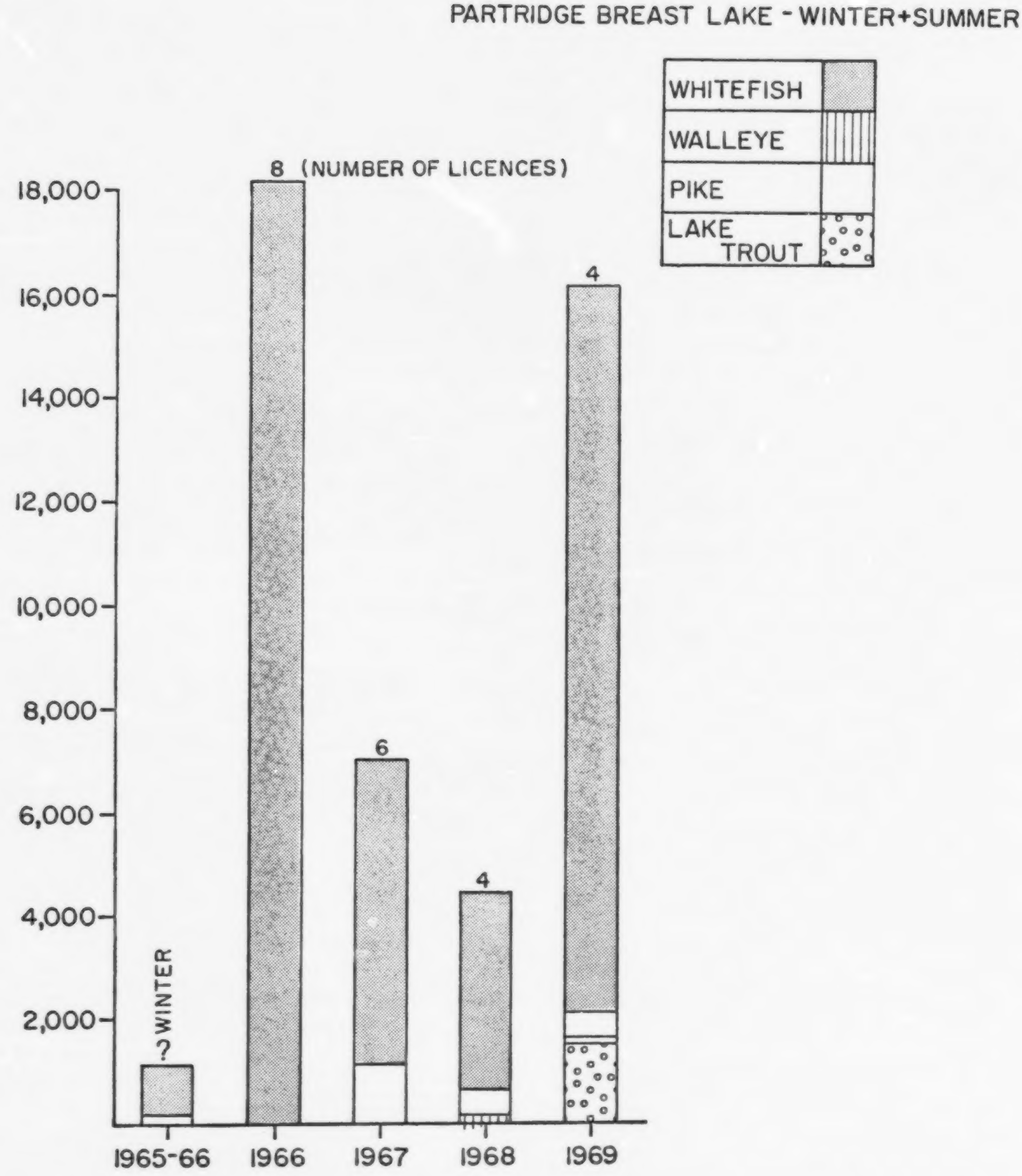

FIGURE 2: Summer commercial fish production on Partridge Breast Lake by year and species (the 1965-66 winter production is also shown).

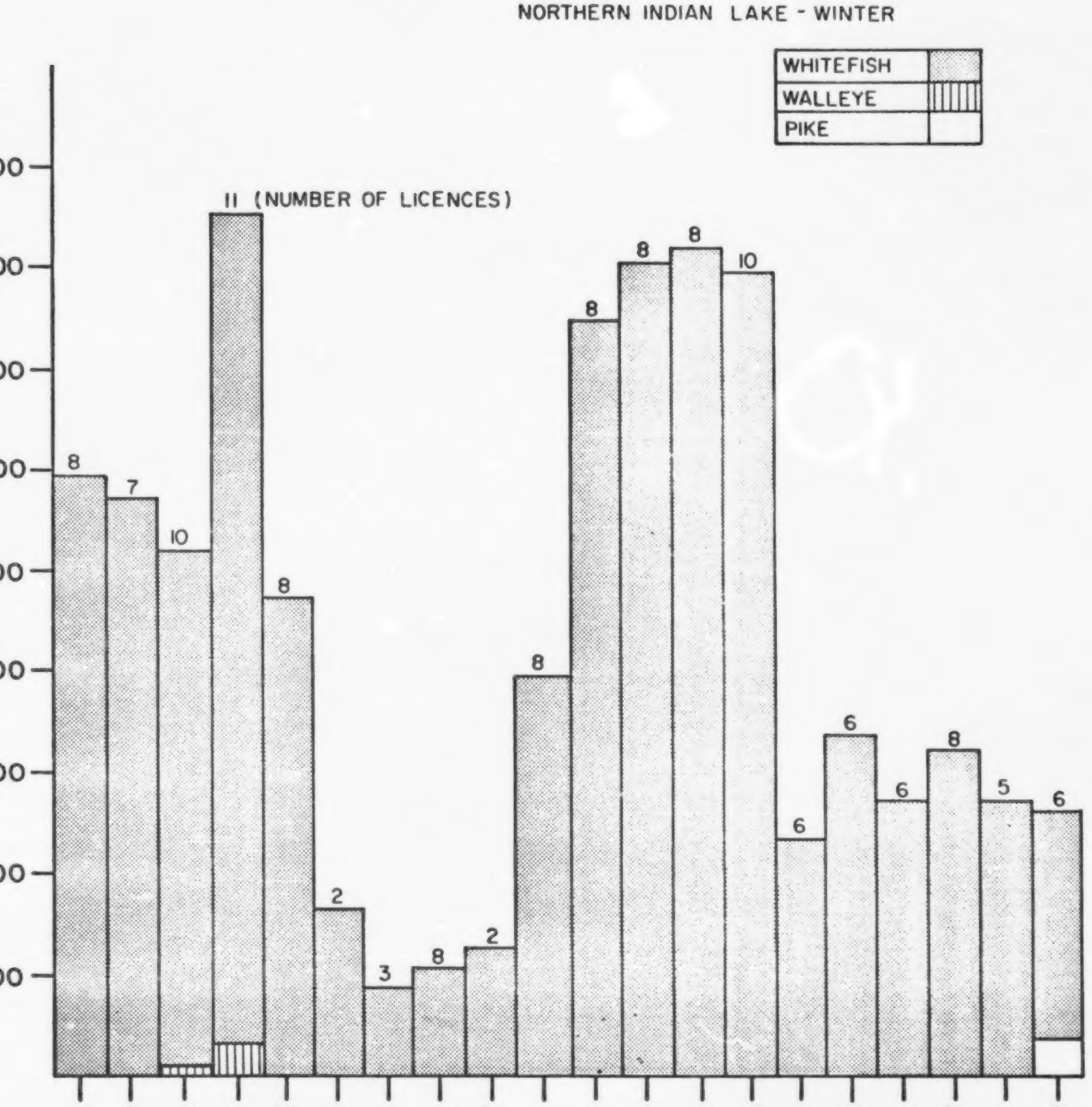

FIGURE 3: Winter Commercial fishery production on Northern Indian Lake by year and species.

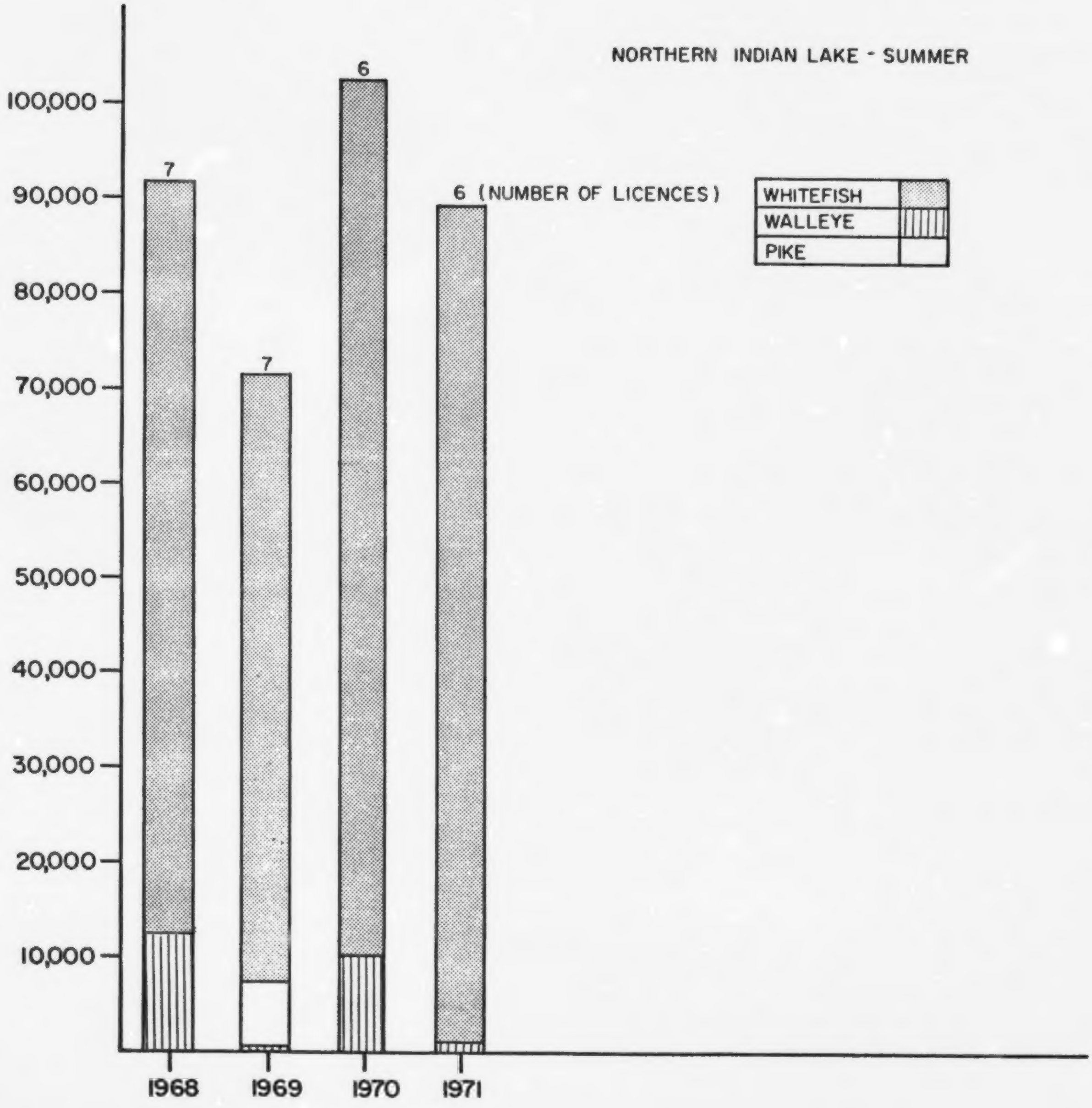

FIGURE 4: Summer commercial fishery production on Northern Indian Lake by year and species.

The fishery in general appears to be healthy and production has exceeded the quota in three of the last five years. The yield on the lake averages 0.576 lbs per acre of which 99.5% are whitefish, 0.3% trout and 0.2% pike (Wickstrom and Merner, 1970).

Until 1972 fish from Northern Indian Lake were flown to Ilford and then transported to Winnipeg by train. During the 1972 summer season the fishery was brought under the South Indian Lake Co-op Fisheries Ltd., and fish were to be flown to Loon Narrows and then transported to Winnipeg with the Southern Indian Lake production. Difficulties arising during the first years were overcome in 1973 and the latter system appears to be running smoothly at present.

The value of the fishery has varied from $27,076 during the 1961-62 winter season (8 licences) to $2,342 during the 1955-56 season.

2-3 Fidler Lake:

The winter fishery began on Fidler Lake in 1959-60 and continued until 1968-69. There has been a summer fishery from 1969 to 1971. The production data for the above seasons are summarized in figures 5 and 6. As for Northern Indian Lake the fishermen usually came from Ilford and before 1972 the fish were shipped by air to Ilford. At present the fish are shipped by air to Loon Narrows on Southern Indian Lake and from there to Leaf Rapids. The quota of 25,000 lbs of whitefish and pickerel has

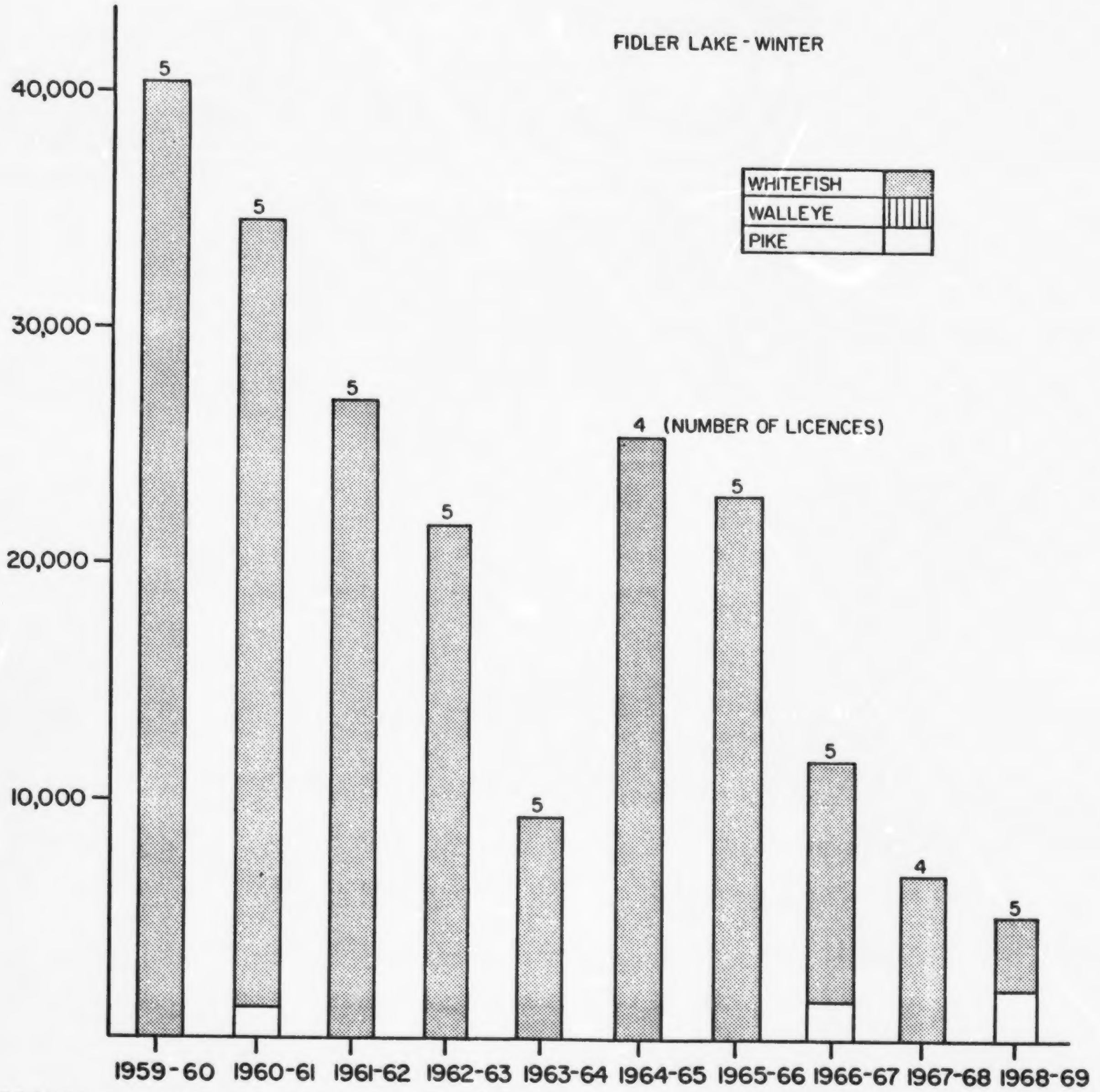

FIGURE 5: Winter Commercial fishery production on Fidler Lake by year and species.

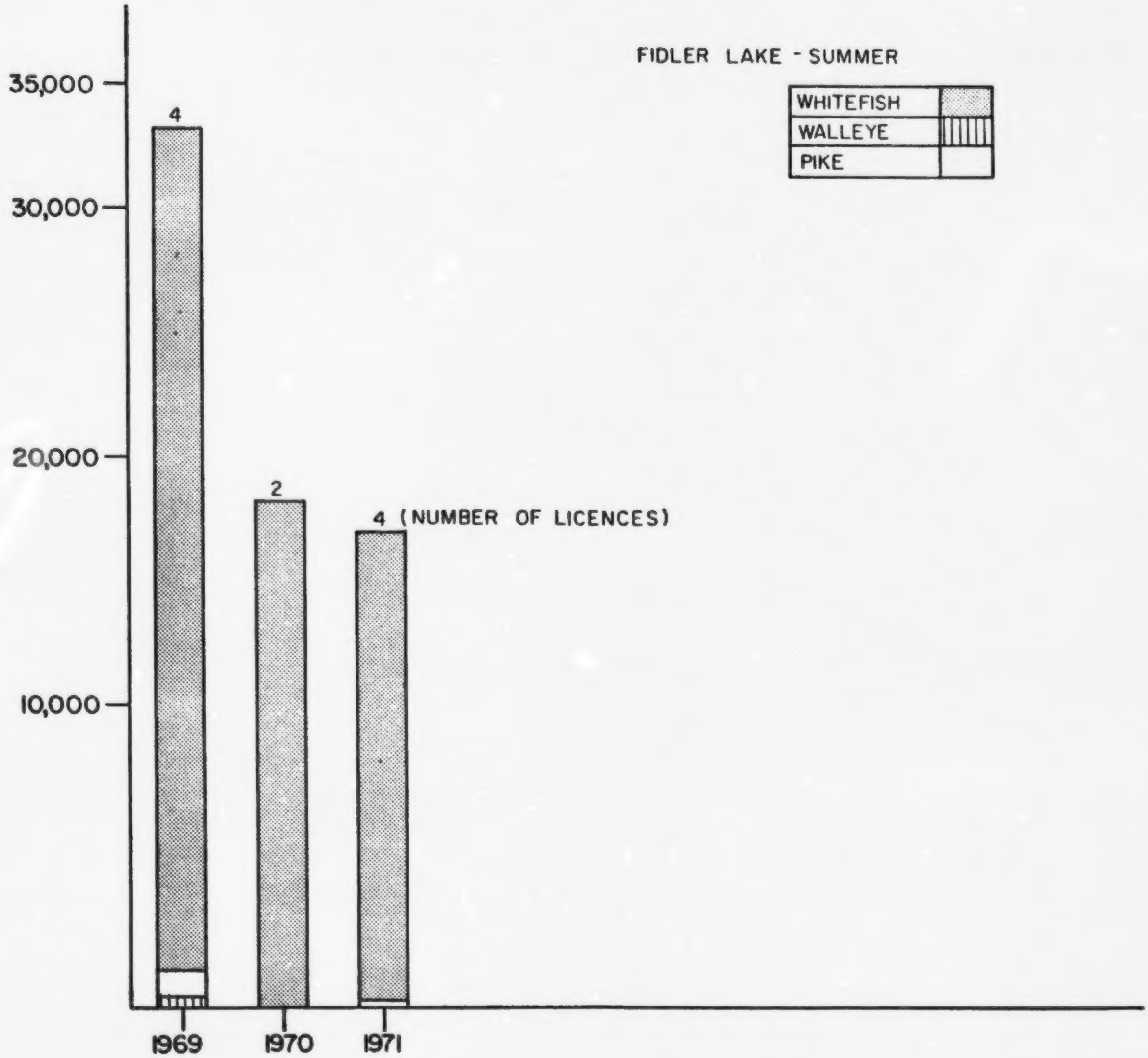

FIGURE 6: Summer commercial fishery production on Fidler Lake by year and species.

been exceeded in five of the 13 seasons the lake has been fished and the yield averages 1.63 lbs/acre of which 98% are whitefish, 2% are pike and 0.13% trout (Wickstrom and Merner, 1970).

Usually 5 licences are issued for the lake and the value to the fishermen has ranged from $1,076 for the 1968-69 winter season to $8,605 for the 1969 summer season.

2-4 Billard Lake:

A quota of 15,000 lbs of whitefish and pickerel was established on Billard Lake in 1965 and the lake was first fished in 1966. In 1967 and 1968 fishing was curtailed and in 1969 to 1971 the lake was again fished. The production is summarized in figure 7. Fish transportation has followed the same pattern on Billard Lake as on Fidler and Northern Indian. The yield for the lake averages 3.84 lbs/acre of which 67% are whitefish, 26% are pike and 7% are pickerel (Wickstrom and Merner, 1970).

The fishery has averaged three licences per season and the value to the fishermen has varied from $1,192 in 1966 to $4,400 in 1969.

2-5 Present Status of Lower Churchill Fishery:

The production on the lower Churchill lakes for 1972, 1971 and 1970 is summarized in Table 1. The low production in 1972 was caused by discontent among the fishermen because they were told to deliver their catches to Southern Indian Lake rather than Ilford.

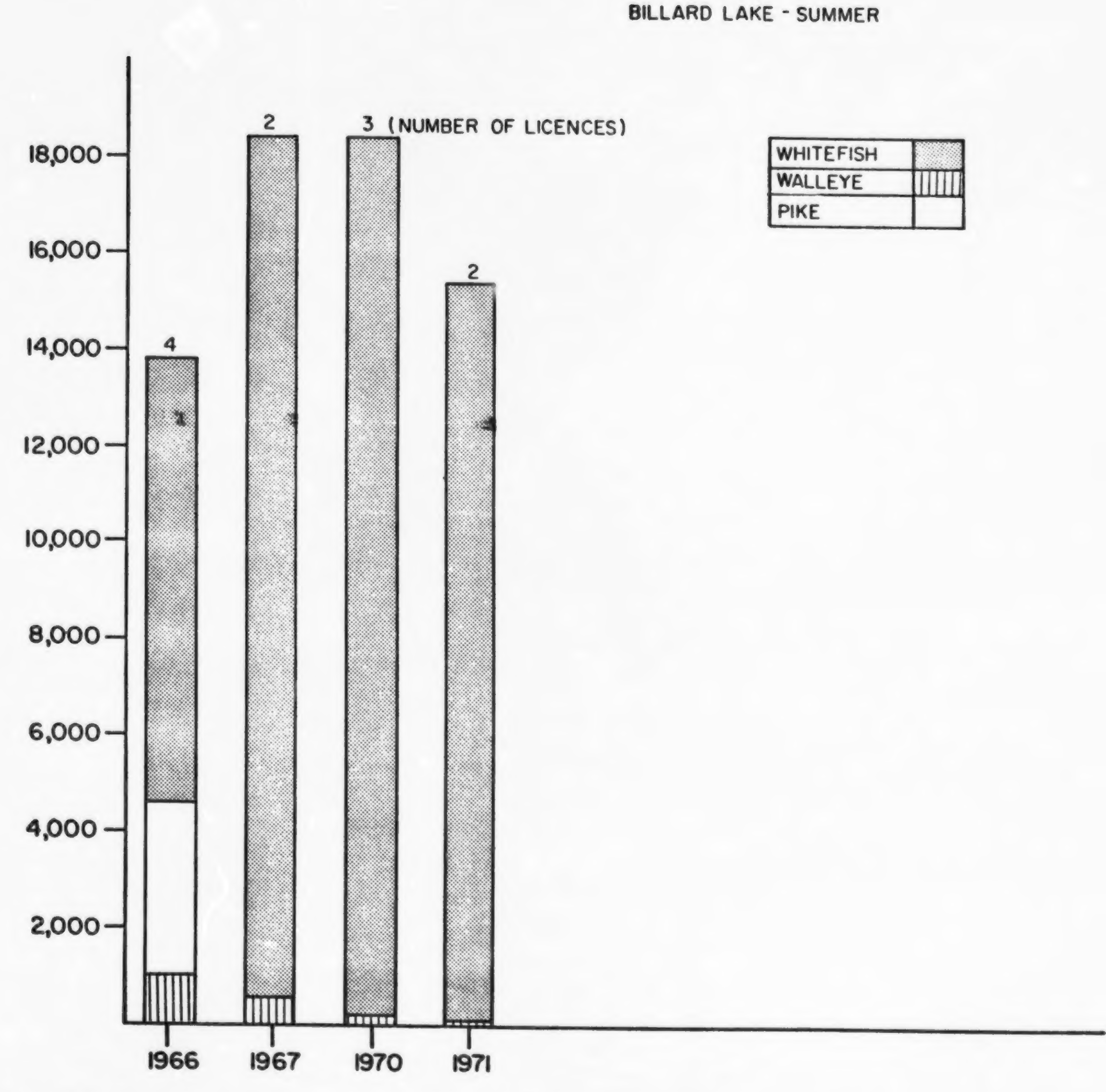

FIGURE 7: Summer commercial fishery production on Billard Lake by ye
and species.

Table 1. Summary of the commercial production on the four lower Churchill lakes for 1972, 1971 and 1970.

Lake	Quota	Production		
		1972	1971	1970
Partridge Breast	20,000	-	-	-
Northern Indian	90,000	62,900	89,300	102,200
Fidler	25,000		17,400	18,200
Billard	15,000		15,400	18,400
	150,000	62,900	122,100	139,500
% of total quota		42%	81%	93%

During the same year lack of coordination of air transportation caused several shipments to spoil.

The fishery on these lakes appears, however, to be out of danger from over-exploitation although the average yield-per-acre are in most cases lower than other Churchill River lakes.

The lower Churchill Lakes contribute on the average 0.5% of the total summer production and 0.37% of the total yearly production for Manitoba.

2-6 Impact of the Diversion:

The major impact of the diversion on the lower Churchill River Lakes will be the lowering of water levels in these lakes. The reductions in areas and levels are shown in Table 2. In relation to the commercial fisheries these lower levels will, first be very demoralizing to the fishermen, second produce countless navigational hazards and third result in a considerable reduction in production.

Assuming the present effort is maintained after diversion and assuming fish production in the lakes remains near the present levels we can expect as much as a 60% reduction in the total commercial production in the lower Churchill River Lakes (Table 2). It is the author's opinion that the reduction in production may even be higher. Once confronted with the new hazards and lower landings the fishermen will very likely stop fishing the area or at least there will be a reduction in effort. There is also a

The production estimate is only valid if the present effort is maintained.

Lake	Present Elevation* (ft)	Post-diversion Elevation* (ft)	Present Area** (Acres)	Post-diversion Area** (Acres)	Average Yield*** (lb/acre)	Average Production*** (lbs)	Post-diversion Production (lbs)
Partridge Breast	803	793	5,888	3,584	0.96	9,000	3,440
Northern Indian	774	763	35,452	21,696	0.58	28,800	12,586
Fidler	759	751	9,587	2,303	1.63	15,400	3,754
Billard	622	613	3,589	2,600	3.84	13,800	9,984
						67,000	29,764

* Annon. Water level and flow information lower Churchill River Lakes.

** Pers. Comm. Helen Ayles.

*** Wickstrom and Merner, 1970.

chance that the productivity of several of the lakes will be reduce leading to smaller population of the commercial species and a further reduction in production.

Overall it would appear that if the lakes are fished after the diversion there will be a reduction in commercial fish landings from the area of from 60 to 75%.

2-7 Mitigation:

One mitigation measure that would help maintain the commercial fisheries of the lower Churchill River Lakes at their present levels is the construction of fixed crest weirs at the outlet of each lake in an attempt to maintain the present lake levels. This would be very expensive and must be viewed in light of the fact that this 60 to 75% reduction in production will result in an approximate 0.2% reduction in the total Manitoba fishery. On the other hand the fishermen who depend on these lakes for a livelihood will have their incomes severly curtailed by the reduced production and some compensation should be provided for this reduction.

3. DIVERSION ROUTE LAKES

3-1 Pemichigamau Lake:

In 1963 Pemichigamau Lake was assigned a quota of 10,000 lbs of whitefish and pickerel for a winter and summer fishery, with preference to be given to residents of Nelson House for licences. To date there has been no record of a commercial fish on the lake.

3-2 Rat Lake:

Rat Lake supports the largest commercial fishery along t diversion route. Although production records date to 1951 the first quota was established at 50,000 lbs of whitefish and walle in 1953, in 1962 this was increased to 100,000 lbs and in 1971 i was decreased to 45,000 lbs. The summer fishery has been pursue intermittently from 1951 to the present with the highest product being 103,300 lbs in 1963 and the lowest 8,900 lbs in 1965 (Figu 8). The winter seasons have also been intermittently, beginning in 1956-57 and continuing until 1966-67. The highest winter production was 26,100 lbs in 1966-67 and the lowest 9,200 lbs in 1960-61. The average yield for the lake is 2.691 lbs/acre of which 78% is whitefish, 13% is walleye and 9% is pike (Wickstrom and Merner, 1970).

There are on the average 9 fishermen during the summer season. The highest value to the fishermen for the summer season was $5,668 in 1970 and the lowest was $470 in 1965. The average ry

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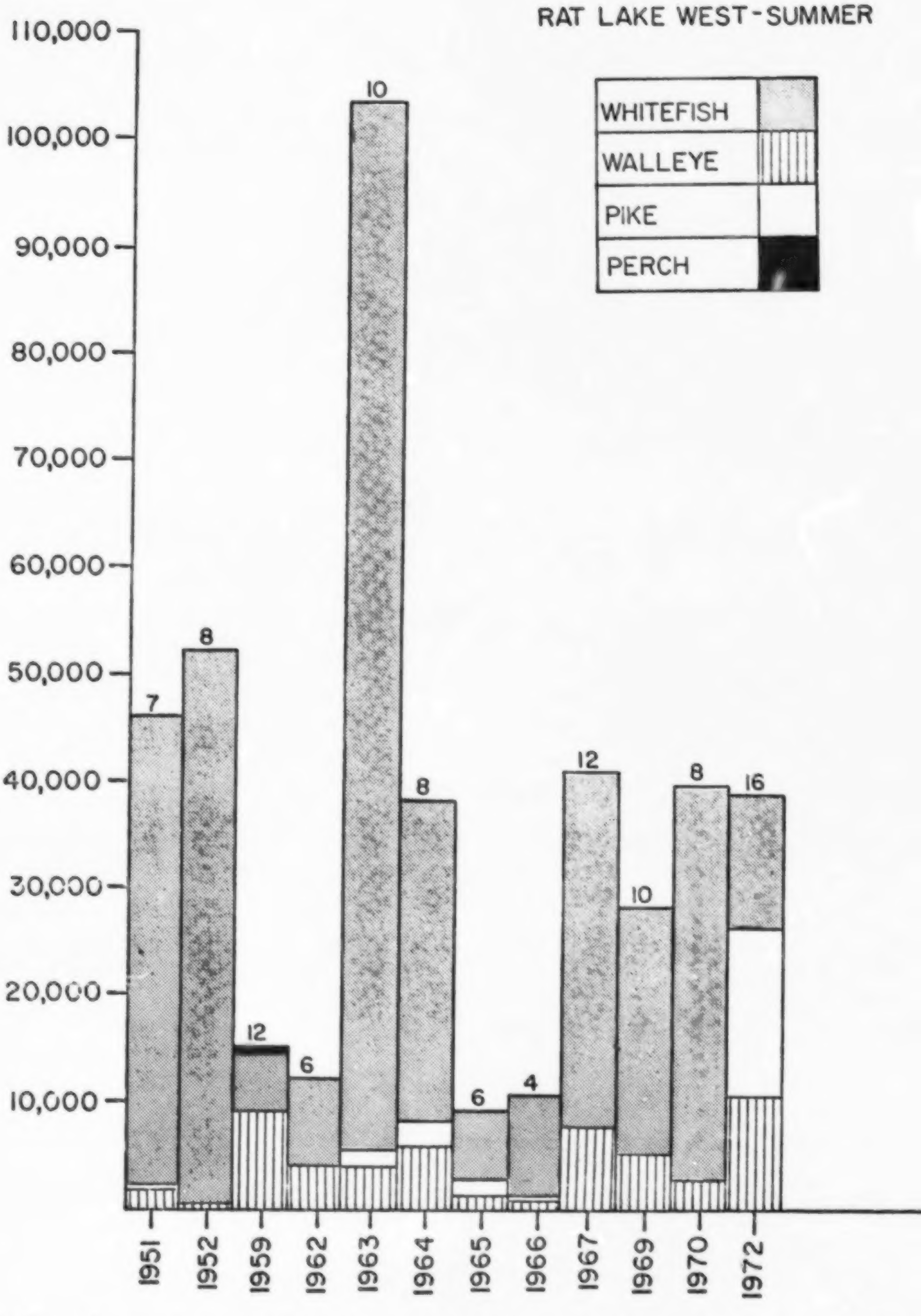

FIGURE 8: Summer commercial fishery production on Rat Lake Wes
year and species.

number of fishermen for the winter fishery is 6 with the highest value being $3,271 in 1966-67 and the lowest $746 in 1958-59.

3-3 Notigi Lake:

Notigi Lake was first fished during the 1945-46 and 1946-47 winter season (Figure 9). The first summer season was in 1958 and the summer seasons continued intermittently until 1966 (Figure 10). The original summer quota was 15,000 lbs of whitefish and pickerel increasing to 25,000 in 1959 and dropping to 10,000 in 1968. The maximum production for the lake was 27,900 lbs during the 1959 summer season and the minimum was 4,000 lbs during the 1946-47 winter season. The average yield for the lake is 1.63 lbs/acre of which 71% are whitefish, 17% pickerel and 12% pike (Wickstrom and Merner, 1970).

The average number of licences on the lake is 5 for the summer and 4 for the winter seasons. The value to the fishermen was a maximum of $2,794 during the 1959 summer season and a minimum of $228 during the 1965 summer season.

3-4 Wapisu Lake:

In 1946 a quota of 30,000 lbs of whitefish and pickerel was set for a summer and winter fishery on Wapisu Lake. To date no commercial landings have been recorded for the lake.

3-5 Wuskwatim Lake:

The first commercial production on Wuskwatim Lake was

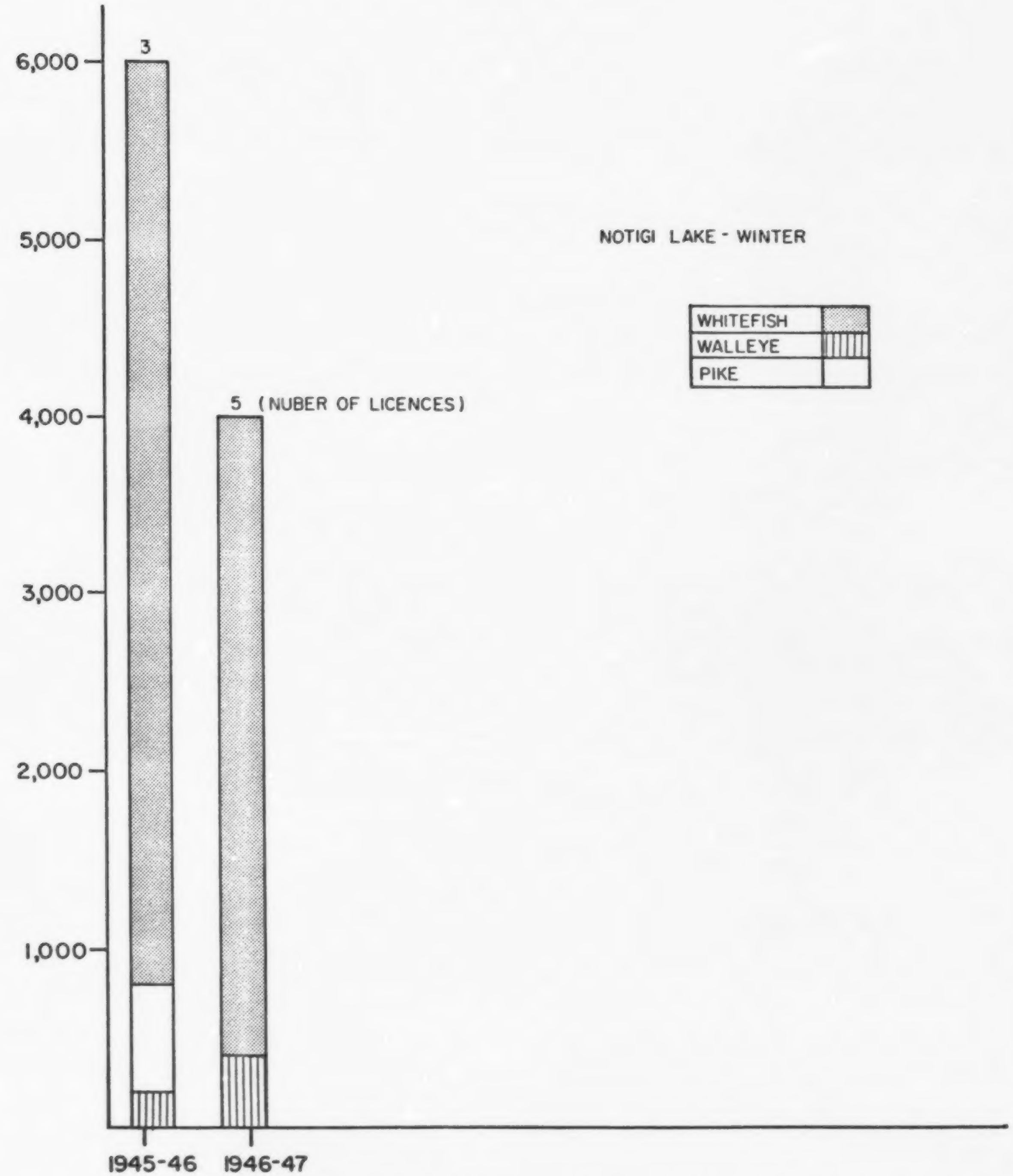

FIGURE 9: Winter commercial fishery production on Notigi Lake by year and species.

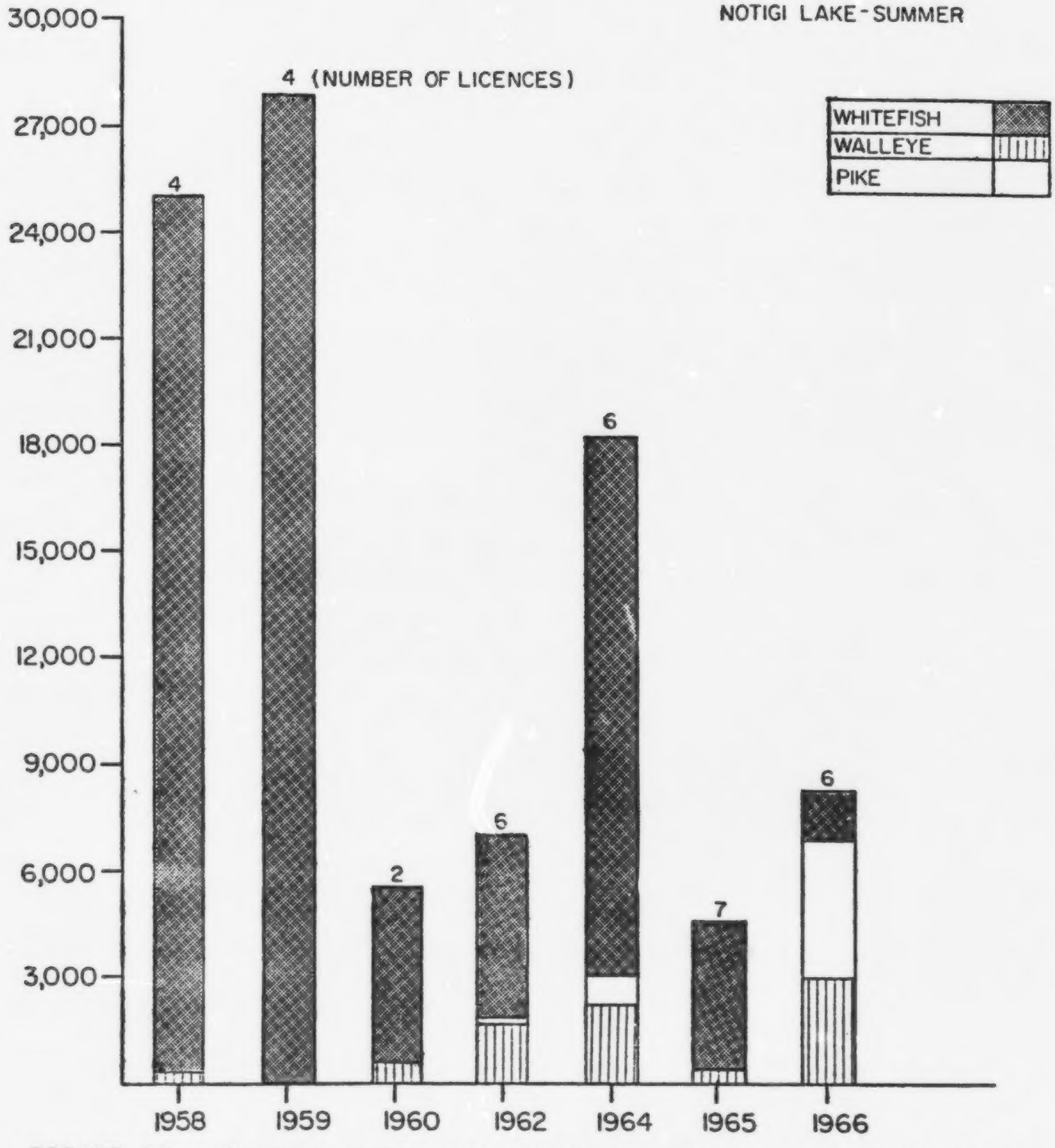

FIGURE 10: Summer commercial fishery production on Notigi Lake by year and species.

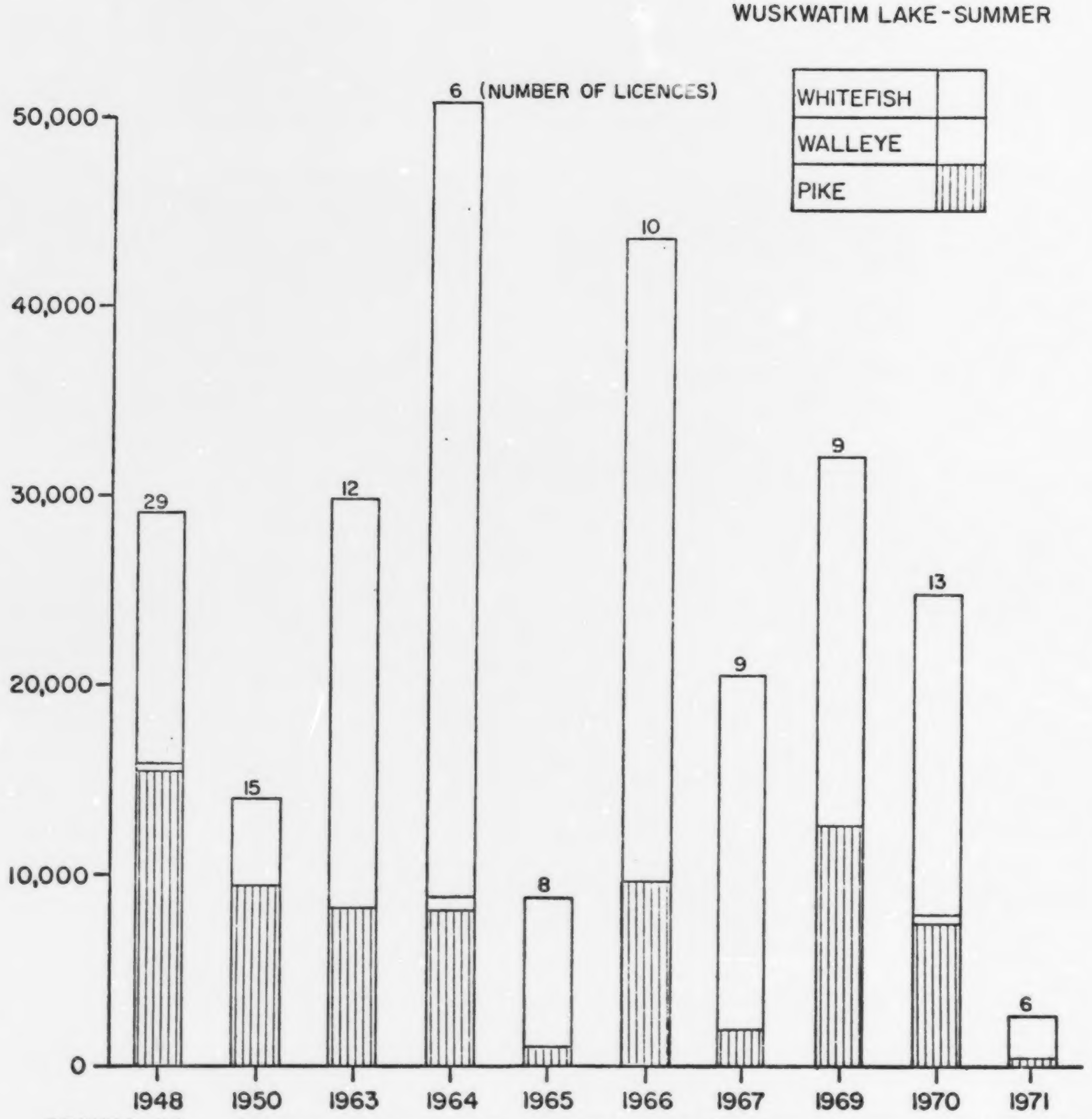

FIGURE 11: Summer commercial fishery production on Wuskwatim Lake by year and species.

reported during the 1948 summer season. The lake has been fished intermittently from then until the 1971 summer season. No winter production has been reported. The quota of 40,000 lbs of whitefish and pickerel was exceeded in 1964 and 1966 (Figure 11). The highest production was 50,700 lbs in 1964 and the lowest 2,200 lbs in 1971. The average yield for the lake is 1.94 lbs/acre of which 80% are whitefish and 18% are pickerel (Wickstrom and Merner, 1970).

The highest value to fishermen was $4,448 in 1970 and the lowest $224 in 1971. There is an average of 12 fishermen per year.

3-6 Mynarski Lakes:

There are two quotas and areas for the Mynarski Lakes. The Mynarski Lakes (east) have a winter quota of 15,000 lbs of whitefish and pickerel. The first season in which production was recorded was 1964-65 and the last 1971-72 (Figure 12). The highest production was in 1964-65 with 20,300 lbs and the lowest in 1971-72 with 500 lbs. The lakes appear to be extremely productive with an average yield of 5.99 lbs/acre, 88% of which is whitefish, 8% pickerel and 4% pike (Wickstrom and Merner, 1970). During 1963 and 1964 there was a summer season on Mynarski Lakes (east) producing 30,500 lbs and 52,800 lbs respectively.

The average number of fishermen on the lakes is 5. The highest value to the fishermen was $4,806 during the 1964 summer season, the lowest, $104 during the 1971-72 winter season.

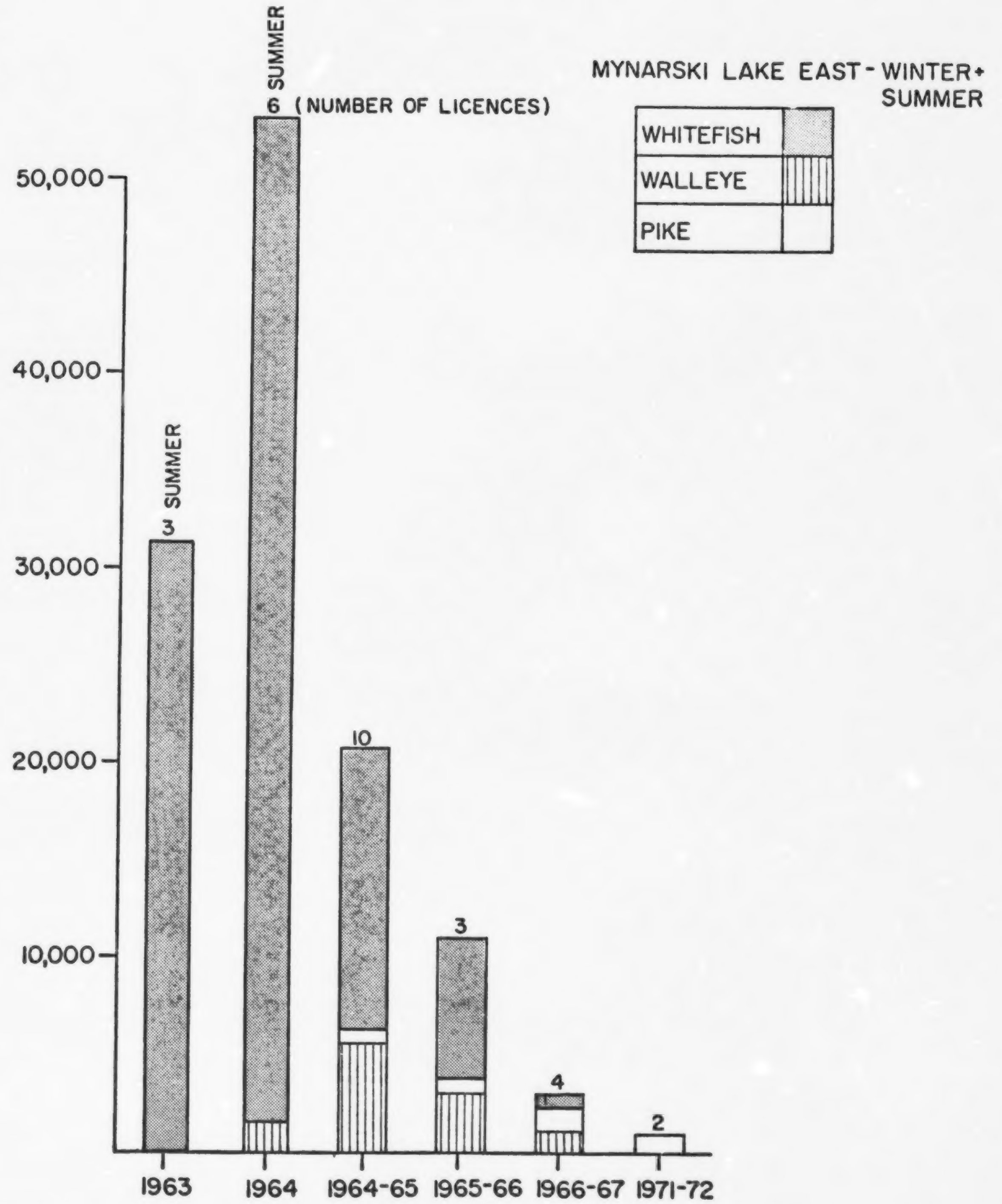

FIGURE 12: Winter commercial fishery production on Mynarski Lake East (also shown is summer production for 1963 and 1964).

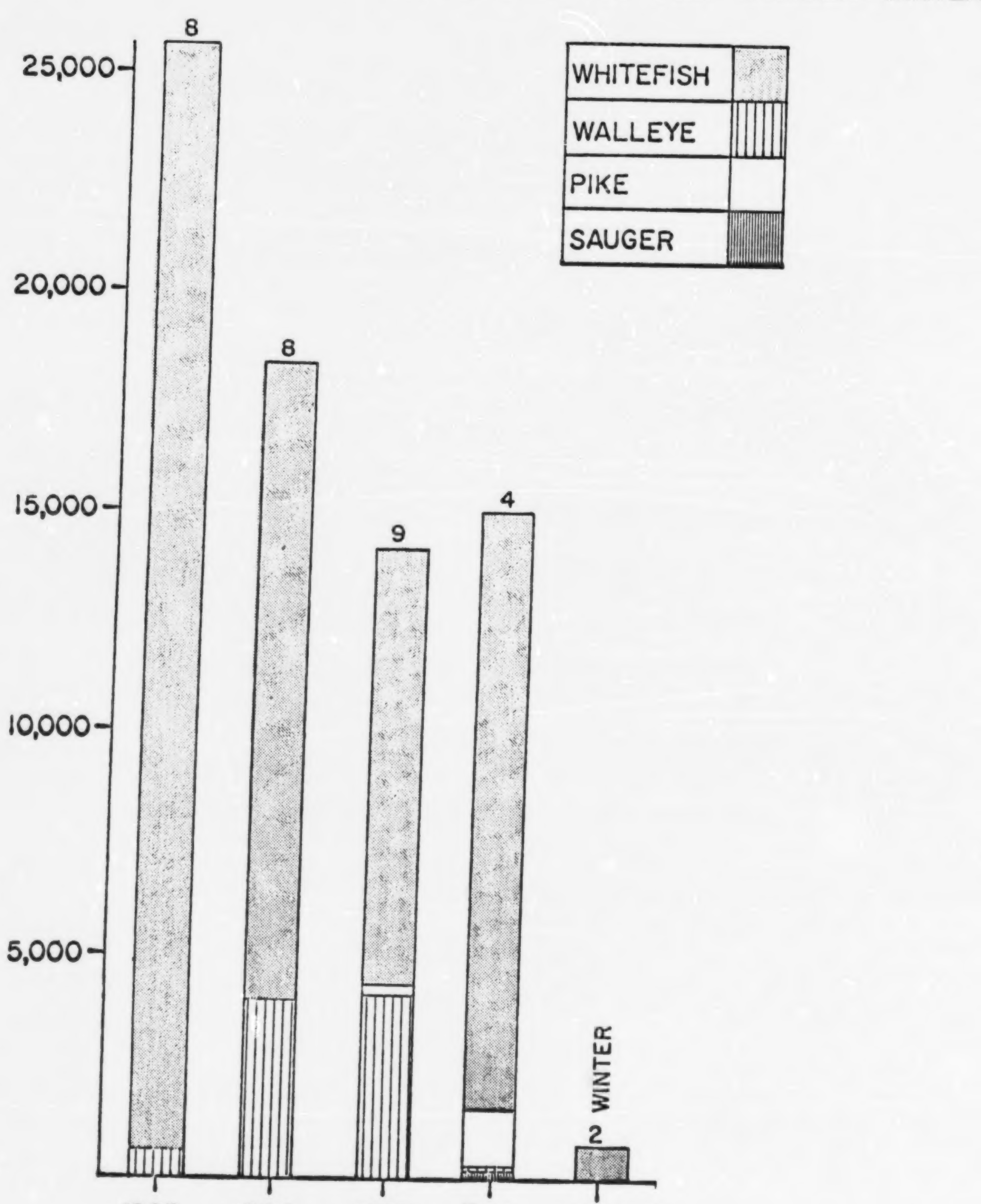

Figure 13: Summer and winter commercial fishery production on Mynarski Lake West.

The Mynarski Lakes (west) have a 25,000 lbs quota for whitefish and pickerel during the winter and summer season. The first production was recorded during the 1965 summer season (Figure 13). One winter season has been recorded in 1971-72. The highest production was 25,500 lbs during 1965 and the lowest 500 lbs during the 1971-72 winter season. The average yield is extremely high at 6.9 lbs/acre of which 85% are whitefish, 15% walleye and 0.3% pike (Wickstrom and Merner, 1970).

There are on the average 7 fishermen per year with the highest value to the fishermen of $2,220 in 1966 and the lowest $104 in 1971-72 winter season.

3-7 Present State of the Fishery:

At present all the fishermen on the above lakes are from Nelson House. Prior to 1972 the production from these lakes was flown to Thompson and from there taken to Winnipeg by Rail. In 1972 these lakes came under the jurisdiction of the South Indian Lake Co-op Fisheries Ltd. and from then to the present all production is flown from the lakes to Leaf Rapids and from there is shipped with the fish from Southern Indian Lake.

As can be seen from Table 3 the lakes on diversion route for the last 3 years have not produced anywhere near their capacities. The yields/acre are usually high so the lack of production is most likely related to lack of effort. The small quotas and distance from handling facilities of the lakes may also contribute

Table 3. Summary of the commercial production on the diversion route lakes for 1972, 1971 and 1970.

Lake	Quota (lbs)	1972 (lbs)	1971 (lbs)	1970 (lbs)
Pemichigamau	10,000			
Rat	45,000	38,600		39,500
Notigi	10,000			
Wapisu	30,000			
Wuskwatin	40,000		2,400	24,800
Mynarski Lakes (east)	15,000	500		
Mynarski Lakes (west)	25,000	500		
	175,000	39,600	2,400	64,300
% of total quota		23%	1%	37%

to the limited effort exerted. As is the case for most northern Manitoba commercial fisheries there is little chance of over-exploitation and the production could be increased with increased effort.

3-8 Impact of the Diversion:

Table 4 summarizes the pre- and post-diversion water levels and lake areas on the diversion route. As can be seen from the data on lake levels there will be extensive increases in lake levels not only in reservoir lakes but in the lakes downstream from the reservoir. The present lake area will comprise only 19% of the reservoir area. The impacts on the commercial fishery will be extensive. Considering the extensive areas of flooded timber it will be difficult if not impossible to utilize gillnets in the reservoir. Gill nets are extremely vunerable to debris both floating and sunk and it is impossible to fish with them over areas of flooded timber. There will be limited if any access to the new shorelines and there may in places be as much as 2 miles of flooded timber between the present and new shorelines. This will make navigation in the reservoir very difficult and hazardous. The present fish camps on Rat, Notigi and the Mynarski lakes will be flooded and the building of new camps will be hampered by the accessibility of the new shoreline. The above conditions will in the author's opinion, lead to an immediate collapse of the commercial fishery in the diversion route lakes. It is unlikely that

Table 4. A summary of the pre- and post-diversion conditions on the diversion route lakes.

Lake	Pre-Diversion Area*	Post-Area*	Pre-Diversion Level**	Post-Diversion Level**	
				Min.	Max.
Pemichigamau	4,812	176,000	815	839.5	847
Rat	21,056	176,000	815	839	847
Notigi	3,712	176,000	794	838	847
Mynarski	9,728	176,000	825	839	847
Wapisu	10,112		787	794	813
Wuskwatin	11,456		758	763	777
Three Point & Foot Print			778	800	810

* Personal Communication Helen Ayles

** Preliminary Data from Manitoba Hydro (March 7, 1974) a fishery could be reestablished before the shorelines have stabilized and the standing timer has been removed from extensive areas of the new reservoir.

The increased flows will also cause extensive raises in the levels of Wapisu, Three Point, Foot Print and Wuskwatim Lakes. The comments on the reservoir also apply to the predicted collapse of the fishery on Wuskwatim Lake.

No data have been collected on the domestic fishery on Foot Print Lake by residents of Nelson House. This fishery will also be hampered by the increased water levels and resulting flooding.

Over all the commercial fishery on the diversion route lakes could be reduced by 90 to 100% after diversion.

3-9 Mitigation:

Extensive clearing within the reservoir and on other diversion route lakes has already been ruled out by monetary restraints. Therefore, the only applicable mitigation measures will be compensation for their losses to the commercial fishermen who now pursue these fisheries. Along with this program there should also be a compensation program initiated to reimburse fishermen who attempt to fish the reservoir for losses and damaged equipment. The owners of fish camps on these lakes should also be reimbursed for the loss of their facilities.

In the area of Nelson House there should be provisions for "safe-landing areas" the location and size of which should be determined by the local people. All warfs and docking facilities flooded or damaged by the higher lake levels should also be replaced.

4. SPORT FISHERY

There is little if any sport fishing on the lower Churchil River above Billard Lake. There has been some sport fishing for Arctic char on the river near the port of Churchill but the extent of this is unknown. Two of the largest Arctic char angled in Manitoba have come from the Churchill River and weights were 6 lbs and 5 lbs 2 ozs the former angled in 1961 and the latter in 1969 both by residents of Fort Churchill. This tends to indicate a sport fishery could easily be developed in the area.

The indications from the experimental fishing crews that worked the lower Churchill Lakes during the summer of 1973 are that the potential for sport fishing is slightly less than Souther Indian Lake (Weagle, 1973). Although lake trout are present in the area they are not plentiful enough to induce the development of lodges and the angling for pike and walleye is not good enough to offset the remoteness of the locations.

Similarly on the diversion route the fishing is not overly productive. The experimental fishing crews encountered good walleye catches on the Mynarski Lakes but the fish were not of trophy size. Aside from the Thompson area there is very little sport fishing pressure. In this area there are usually several trophy size pike (over 18 lbs) taken each year.

After diversion the char runs in the lower Churchill River may be reduced, lowering the potential for a sport fishery there.

On the diversion route there will most likely develop a "tail-race fishery" for walleye and pike at Notigi and the potential for a pike sport fishery in the reservoir will be excellent. If boat access areas near the Notigi structure are provided and clearing in the same area is completed it may entice more anglers to the area. The success of this fishery will be slightly overshadowed, however, by the extent of the flooded timber and difficulty of water transport. There will still be excellent pike and walleye fishing in various areas of the Burntwood River although transportation will be more difficult because of the increased water levels.

5. FISH REPRODUCTION

The impact of the diversion on fish reproduction on the lower Churchill lakes is difficult to predict. In relation to walleye it is likely that the lower water levels will have limited affect on their spawning habits. The flows will remain the same in the inflowing streams and even at the lower lake levels it is likely that channels to these streams will be maintained. Whitefish spawning may be adversely affected by the lower levels because of the lack of suitable spawning beds. There will be limited lowering of lake levels in the lower Churchill Lakes between October and March which should maintain the spawn which was deposited. The problems in these areas are more likely to be related to rearing areas than spawning areas and the reestablishment of aquatic vegetation will be very important in this regard.

In the diversion route lakes whitefish reproductive success will be closely related to post-diversion, shoreline stabilization. The author feels there will be at least in the initial years a drastic decrease in whitefish reproductive success (5-10 years). Most of the present walleye spawning sites in these lakes will be flooded. Again there is likely to be drastic reductions in the reproductive success. It is not known how the walleye populations will respond to this and no prediction will be made on their ability to adapt to completely new spawning areas. It may be advisable to conduct an extensive clearing program along the

Suwannee River to help maintain at least one of the present walleye spawning streams. This would involve the clearing, piling and burning of all material from the present mouth of the river to the point where the new high water level (847') intersects the river and along each bank to the new high water level. Pike will most likely flourish in the new reservoir.

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LAKE WINNIPEG, CHURCHILL AND NELSON RIVERS STUDY BOARD

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